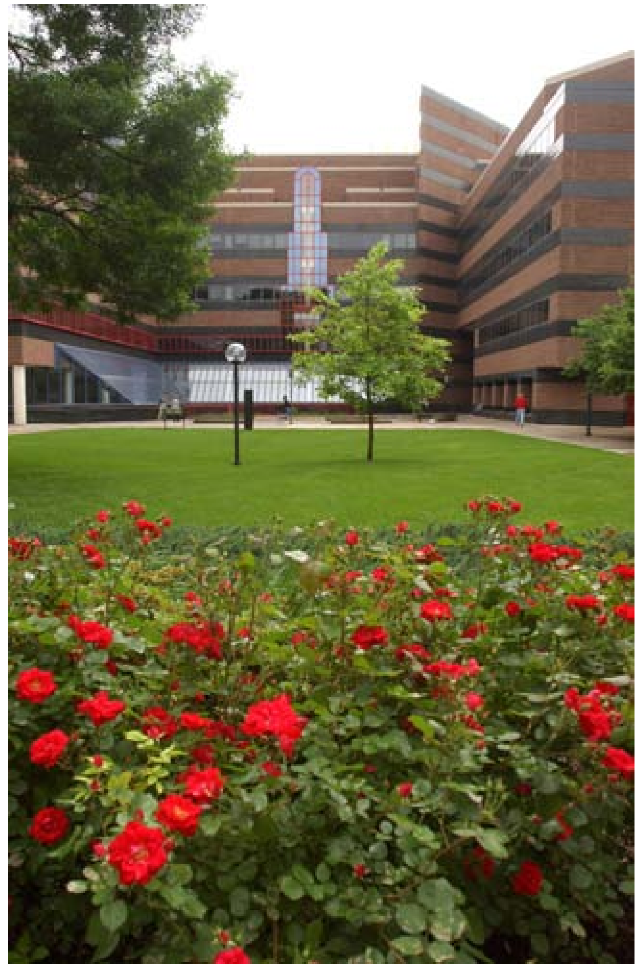
NNIN

Nanoscale Science, Engineering & Technology



2010 NNIN REU Convocation

at the University of Minnesota

August 11-14, 2010

University of Minnesota

NSF

2010 NNIN REU Convocation
University of Minnesota

Wednesday, August 11th

6:00 p.m. .. .. Race Game for Interns — Frontier Hall front desk/main doors

8:00 p.m. .. .. Pizza Dinner for everyone — Electrical Engineering Bldg (EE)

Thursday, August 12th

8:00 a.m. .. .. Breakfast — EE Bldg, atrium area main floor

8:35 a.m. .. .. Welcome: Steve Campbell — EE Bldg, Room 3-180

Announcements

8:45 a.m. .. .. Session T-1 (8 talks) — EE Bldg, Room 3-180

Moderator: Becky von Dissen

10:05 . .. . Break

10:25 . .. . Session T-2 (8 talks) — EE Bldg, Room 3-180

Moderator: Ethan Allen

10:55 a.m. Bakkila, Scott; page 13 .. .. University of Michigan, Ann Arbor
Ferroelectric Thin Films for Reconfigurable RFE in Next Generation Wireless Communications

11:05 a.m. Brunson, Mark; page 14 .. .. Washington University in St. Louis
Generation of a "Clean" Surface on Metallic Nanoparticles for Reliable Toxicity Evaluation

11:15 a.m. Morse, Kelsey; page 14 .. .. Stanford University
Synthetic Antiferromagnetic Nanoparticles for Biosensing

11:25 a.m. Benton, Brian; page 15 .. .. University of Colorado at Boulder
Growth of Graphene Nanostructures on Silicon Wafers

11:35 a.m. Adams, Siatta; page 15 .. .. Howard University
Heterogrowth Junction of Silicon-Germanium and Carbon Nitride

11:45-12:45 .. .. Lunch **EE Bldg, atrium area main floor**

Admin Mtg for Coordinators ***EE Bldg, Room 3-176***

12:45 .. .. Session T-3 (8 talks) **EE Bldg, Room 3-180**

Moderator: Melanie-Claire Mallison

12:45 p.m. Lee, Jason; page 16 .. .. University of Minnesota-Twin Cities
DNA Electrophoresis in Microfabricated Devices

12:55 p.m. Hoerner, Michael; page 16 .. .. University of Colorado at Boulder
Fabrication and Characterizations of Plasmonic Nanostructures for Organic Photovoltaics

1:05 p.m. Ponce de Leon, Philip; page 17 .. .. Stanford University
Surface Treatments to Control the Wettability of Photonic Crystal Bio-Sensors

1:15 p.m. Dunn, Megan; page 17 .. .. University of Washington
Surface Analysis of DNA Microarrays

1:25 p.m. Kuruvilla, Sibu; page 18 .. .. University of Michigan, Ann Arbor
Top-Down Fabrication of Patterned Vertically Aligned Silicon Nanowires

1:35 p.m. Hoffman, Emily; page 18 .. .. Cornell University
Portable Diagnostic Systems for the Purification and Detection of Biomolecules

1:45 p.m. Jordan, Roger; page 19 .. .. University of Washington
Molecular Specific Biosensing Based on Engineered
Quasi-3D Nanostructures Used for Cancer Diagnostics

1:55 p.m. Downing, Fraser; page 19 .. .. The University of Texas at Austin
Immunomagnetic Detection of Circulating Tumor Cells using a Microfluidic Chip

2:05 .. .. Break

2:25 .. .. Lynn Rathbun: NSF Fellowships

2:40 .. .. Session T-4 (6 talks) **EE Bldg, Room 3-180**

Moderator: Kathryn Hollar

2:40 p.m. Phare, Christopher; page 20 .. .. Cornell University
Single-Layer Graphene Contacts to Pentacene Organic Thin Film Transistors

2:50 p.m. Worley, Barrett; page 20 .. .. Georgia Institute of Technology
Advanced Chip-to-Chip Interconnect

3:00 p.m. Klemm, Angeline; page 21 .. .. University of Minnesota-Twin Cities
Fabrication of Magnetic Tunnel Junction Based Spintronic Devices

3:10 p.m. Wallace, Margeaux; page 21 .. .. Georgia Institute of Technology
Low Stress Oxides for use in Microfabricated Ion Traps for Quantum Computation

3:20 p.m. Augustine III, Hilton; page 22 .... **Howard University**
Process Development for Writing sub-100nm Line Widths Using a SEM

3:30 p.m. Wingfield, Amber; page 22 .... **Howard University**
Fabrication of a Gallium Nitride NanoFET

3:40 .... Break

4:00 .... Session T-5 (4 talks) EE Bldg, Room 3-180

Moderator: Michael Deal

4:00 p.m. Swider, Natalie; page 23 .... **University of Michigan, Ann Arbor**
Characterization of High Aspect Ratio Silver Micromachining for Tunable RF Filters

4:10 p.m. Meza Roman, Jhim; page 23 .... **Harvard University**
Lifetime of Charge Carries in Silicon Nanowires

4:20 p.m. Fiedler, Callie; page 24 .... **University of Colorado at Boulder**
Three-Dimensional Super-Resolution Using a Phase Mask Fabricated via Grey-Level Lithography

4:30 p.m. Hammack, Audrey; page 24 .... **University of California, Santa Barbara**
Probing Nano-Scale Volumes and Vesicular Membrane Solvent Dynamics Via Selective Enhancement of Nuclear Magnetic Resonance Signal by Dynamic Nuclear Polarization

4:40 p.m. .... End of talks for the day

5:30 p.m. .... Bus pick-up at 5:30 for cruise Frontier Hall

****Staff/Coordinators: be sure to be to Frontier Hall by 5:15pm***

9:30 p.m. .... Return bus ride from cruise

Friday, August 13th

8:00 .... Breakfast EE Bldg, atrium area main floor

8:35 .... Session F-1 (8 talks) EE Bldg, Room 3-180

Moderator: Brandon Lucas

8:35 a.m. Wardwell, Clare; page 25 .... **Arizona State University**
Micropore Immunosensors for Fast Disease Diagnostics

8:45 a.m. Watson, Erin; page 25 .... **University of California, Santa Barbara**
Designing Nano-Engineered Substrates to Probe Cell Organization, Motion and Traction Forces

8:55 a.m. O'Connell, Fiona; page 26 .... **Georgia Institute of Technology**
Fabrication of Gold Nanoparticles Using Electron Beam Lithography: Effect of Development Conditions on Shape and Resolution

9:05 a.m. Jones, Kristen; page 26 .... **Washington University in St. Louis**
Response of Microorganisms to Cu-Doped TiO_2 NPs Under Different Light Conditions

9:15 a.m. Wang, Jennifer; page 27 .... **Washington University in St. Louis**
Porous Microbeads as Three-Dimensional Scaffolds for Tissue Engineering

9:25 a.m. Watanabe, Masaki; page 27 .... **University of Michigan, Ann Arbor**
Cell Viability and Morphology on Carbon Nanotube Microstructures

9:35 a.m. Mirts, Evan; page 28 .... **Arizona State University**
High Resolution SPR Microscopy Based Microarray

9:45 a.m. Lowe, Christopher; page 28 .... **Arizona State University**
Nanotherapeutics for Advanced Cancer Disease

9:55 .. .. Break

10:15am .. .. Session F-2 (8 talks) EE Bldg, Room 3-180

Moderator: Angela Berenstein

10:15 a.m. Palomino, Gabriel; page 29 .. .. The University of Texas at Austin
Semiconductor Nanocrystal Inks for Printed Photovoltaics

10:25 a.m. Treml, Benjamin; page 29 .. .. University of Minnesota-Twin Cities
Template Stripping for High Thoughput Fabrication of Nanohole Arrays

10:35 a.m. Campbell, Gavin; page 30 .. .. The University of Texas at Austin
Growth and Characterization of Nanoparticle Enhanced Tunnel Junctions

10:45 a.m. Dawley, Natalie; page 30 .. .. The Pennsylvania State University
Aluminum Induced Crystallization of Silicon on Quartz for Silicon Wire Array Solar Cells

10:55 a.m. Davis, John; page 31 .. .. Cornell University
Effect of Surface Pre-Treatments on Initial Stages of Tantalum Nitride ALD

11:05 a.m. Tayson-Frederick, Mallory; page 31 .. ..University of Colorado at Boulder
Nanoethics Research and Ethics Education Implementation

11:15 a.m. Krueger, Kendra; page 32 .. ..University of Colorado at Boulder
The Nano Influence: Perspectives of nanotechnologists on how they shape the world around us

11:25 a.m. Lake, Chloe; page 32 .. .. Cornell University
Societal and Ethical Issues Public Service Posters

11:35-1:10 .. .. Lunch & Photo Sessions EE Bldg, atrium area main floor

1:10 .. .. Session F-3 (8 talks) EE Bldg, Room 3-180

Moderator: Katie Hutchison

1:10 p.m. Chung, Brian; page 33 .. .. University of California, Santa Barbara
Material Characterization of Advanced III-V Semiconductors for Nanophotonic Integration

1:20 p.m. Smalley, Joseph; page 33 . .. . University of California, Santa Barbara
Characterization of Materials with Epitaxially Embedded
Nanoinclusions for Thermoelectric Applications

1:30 p.m. Connell, Zachary; page 34 . .. . The Pennsylvania State University
Mechanics of 1-25 nm Thin Films

1:40 p.m. DesHarnais, Marie; page 34 .. .. Howard University
Characterization of Ag-Si Composite for Infrared Photodetectors

1:50 p.m. Chen, Jack; page 35 .. .. Washington University in St. Louis
Characterization of Iron Oxide Integration within Phospholipid Encapsulated Colloids

2:00 p.m. Wachter, Jeremy; page 35 .. .. University of California, Santa Barbara
Sputtered TiW/W Emitter Contact Stack Design in Terahertz Bipolar Transistors

2:10 p.m. Conner, Austin; page 36 .. .. Cornell University
Optimization of Ohmic Contacts to III-N Semiconductor Material

2:20 p.m. Pillers, Michelle; page 36 .. ..Stanford University
Graphene Nanoribbons as Transistors in Nanoelectronic Devices

2:30 .. .. Break

2:50 .. .. Lynn Rathbun: iREU Program EE Bldg, Room 3-180

3:35 .. .. Session F-4 (2 talks) EE Bldg, Room 3-180

Moderator: Trevor Thornton

3:35 p.m. Henderson, Zachary; page 37 .. .. University of Michigan, Ann Arbor
Heterogeneous Integration of p- and n-type Nanowires for Complementary Nanowire Circuits

3:45 p.m. Clapp, Corey; page 37 .. .. The Pennsylvania State University
Fabrication of Locally-Gated Bilayer Graphene Field Effect Transistors

3:55 .. .. Break

4:15 .. .. Session F-5 (7 talks) EE Bldg, Room 3-180

Moderator: Kristy Wendt

4:15 p.m. Le, Chantalle; page 38 .. .. Washington University in St. Louis
Multimodal Optical and MRI Studies with Multifunctional Spinel Nanoparticles

4:25 p.m. Pham, Phi; page 38 .. .. The University of Texas at Austin
Transferring CVD Grown Graphene

4:35 p.m. Lui, Gillian; page 39 .. .. Stanford University
Adhesion of Capillary Underfill Epoxies for Flip Chip Packaging

4:45 p.m. Shi, Meng; page 39 .. .. The Pennsylvania State University
Magnetic Domain Wall in Nanobridges of Ultrathin Manganite Films

4:55 p.m. Twigg, Stephen; page 40 .. .. The Pennsylvania State University
Ion Distribution in Ionomer and High Temperature Ionic Liquid Actuators

5:05 p.m. Mackin, Charles; page 40 .. .. Cornell University
Suspended Graphene Structures on Silicon Carbide Substrates

5:15 p.m. Nelson, Heidi; page 41 .. .. University of Washington
Plasmonic Nanoparticle Dimer Sensors

5:25 .. .. End of talks for the day

6:00 .. .. Games & Dinner Goldy's Gameroom, Coffman Memorial Union

Dinner will be served at 6:30pm

Saturday, August 14th

8:00 .. .. Breakfast EE Bldg, atrium area main floor

8:35 .. .. Kazuo Furuya: NIMS, Japan EE Bldg, Room 3-180

8:50 .. .. Session S-1 (6 talks) EE Bldg, Room 3-180

Moderator: Allison Cargile

8:50 a.m. Fujii, Hiromasa; page 41 .. .. The University of Texas at Austin
Synthesis and Characterization of Oxide Embedded and Surface Passivated Silicon Nanocrystals

9:00 a.m. Romanczuk, Christopher; page 42 .. .. University of Michigan, Ann Arbor
Silicon Phononic Crystals for High Efficiency Thermoelectrics

9:10 a.m. Lee, Ruby; page 42 .. .. Harvard University
Controlling Nanoscale Electronic Variability in ZnO:Al Transparent Conducting Films

9:20 a.m. Mahala, Benjamin; page 43 .. .. Georgia Institute of Technology
Temperature Dependent Growth Properties of Epitaxial Graphene on (000) on SiC

9:30 a.m. **Oghedo, Nkemdilim; page 43** .. ..**University of Washington**
Tuning Graphene Conductivity Using Inorganic Binding Peptides

9:40 a.m. **Bennett, Kathleen; page 44** .. ..**University of Washington**
Engineering Bacterial Proteins for Design of Self-Assembled Nanostructures

9:50 .. .. Break

10:10 . .. . Session S-2 (6 talks) EE Bldg, Room 3-180

Moderator: Nancy Healy

10:10 a.m. **Anger, Richard; page 44** .. .. **Cornell University**
Development of Adv. Carbon Electrodes for use in Microfluidic Vanadium Redox Fuel Cells

10:20 a.m. **Appel, Jennie; page 45** .. .. **Arizona State University**
Real Time Blood Coagulation Sensor

10:30 a.m. **Cantley, Lauren; page 45** .. ..**University of Colorado at Boulder**
Fabrication of Three Terminal Nanomechanical Graphene Switch

10:40 a.m. **Wang, Yingxia; page 46** .. .. **University of Minnesota-Twin Cities**
Encapsulation of Single Cells in a Droplet-Based Microfluidic Device

10:50 a.m. **Wu, Diana; page 46** .. .. **Cornell University**
Improving Quality Factor of Drum Resonators via Gas Confinement

11:00 a.m. **Chase, Steven; page 47** .. .. **Georgia Institute of Technology**
Measurement and Analysis of Blood Platelet Activation within a Microfluidic Device

11:10 . .. . Break

11:30 . .. . Session S-3 (6 talks) EE Bldg, Room 3-180

Moderator: Kathy Gehoski

11:30 a.m. **Satzinger, Kevin; page 47** .. ..**Harvard University**
High Spatial Resolution Kelvin Probe Force Microscopy with Shielded Probes

11:40 a.m. **Alvarez, Narahi; page 48** .. .. **Howard University**
Characterization of Hg and Cu Capped Monolayers

11:50 a.m. **Bersin, Lia; page 48** .. .. **The University of Texas at Austin**
Laminated Anodes and Electron Transport Layers for
Inverted Organic Bulk Heterojunction Solar Cells

12:00 p.m. **Tsukamoto, Takashiro; page 49** .. .. **Georgia Institute of Technology**
Fabrication of Recessed Bond Pad for Scalable Multiplexed Ion Traps

12:10 p.m. **O'Connell, Christopher; page 49** .. .. **Cornell University**
Fabrication of Graphene Structures Using an Atomic Force Microscope

12:20 p.m. **Carroll, Sylvia; page 50** .. .. **Cornell University**
Investigation of the Effects of Base Diffusion in Molecular Glass Photoresist Films

12:30 . .. . Boxed Lunches to go EE Bldg, Atrium area main floor

1:00 .. .. Poster Session Set-up Coffman Union, Mississippi Room (3rd floor)

1:15 .. .. Poster Session Coffman Union, Mississippi Room (3rd floor)

3:15 .. .. Final remarks / Adjourn

3:30 .. .. Free time for everyone

The 2010 National Nanotechnology Infrastructure Network Research Experience for Undergraduates

Convocation Abstracts

in order of presentation

Close-Packed Monolayer of Silica Nanoparticles for use as Etch Mask in LED Active Region

Christina Jones, Engineering Physics, University of Colorado at Boulder

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor
NNIN REU Principal Investigator: Pei-Cheng Ku, Electrical Engr. and Computer Science, University of Michigan, Ann Arbor
Mentor: Michael Kuo, Electrical Engineering and Computer Science, University of Michigan, Ann Arbor
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Light-emitting diodes (LEDs) show promise for efficient solid-state lighting. However, improved efficiency is necessary to compete with current lighting options. Irregular, nanostructured semipolar (NSSP) patterning of the active region in gallium nitride (GaN) LEDs has shown to improve the internal quantum efficiency by 30% compared to planar active regions by reducing polarization charges. This can be optimized by creating a more uniform NSSP pattern and using a less damaging surface treatment. Essential to the patterning is an etch mask that results in periodic, nano-scale dips in the GaN. We report the progress of a nanoparticle, close-packed monolayer for use as this etch mask. Silicon dioxide nanoparticles with 100 nm diameter in a 5 wt. % aqueous solution were spun onto both glass and n-type GaN substrates. Monolayers and mostly close-packed structures were obtained on both substrates, as characterized by SEM. The defects in the GaN and the irregularity of the nanoparticle size and shape limit the uniformity and close-packing of the monolayer.

Transfer of Electron Beam-Patterned Photonic Nanobeam Cavities to Flexible Substrates

Dominique Djanal-Mann
Electrical Engineering, University of Florida

NNIN REU Site: Center for Nanoscale Systems, Harvard University
NNIN REU Principal Investigator: Professor Marko Loncar, School of Engineering and Applied Sciences, Harvard University
NNIN REU Mentor: Ian Burgess, School of Engineering and Applied Sciences, Harvard University
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The recent demonstrations of high-Q/V photonic-crystal nanobeam cavities in low-index materials allows their application in a broad array of material systems (polymers, glasses, etc.). An elastomeric platform for high Q/V cavities has a wide range of potential applications in bio-sensing and microfluidics. We studied the transfer of the electron beam resist ZEP 520, as well as cavities fabricated in it, onto the silicone elastomer poly(dimethyl siloxane) (PDMS, Sylgard 184). Films were deposited on various sacrificial substrates. PDMS bonding was facilitated through deposition of a thin SiO_2 layer on the ZEP film and plasma oxidation of the PDMS surface. The largest percentage of ZEP transferred to the surface of PDMS when silicon was used as the sacrificial substrate, dissolved in a 30% aqueous solution of potassium hydroxide. Oxide adhesion to the ZEP layer was found to be poor, limiting the effectiveness of the transfer process.

Automation of Sample-Positioning and Data-Collection for Pulsed-Laser-Melting Experiments

Edy Cardona, Physics, University of California, Berkeley

NNIN REU Site: Center for Nanoscale Systems, Harvard University
NNIN REU Principal Investigator: Michael Aziz, Applied Physics, School of Engineering and Applied Sciences, Harvard
NNIN REU Mentor: Daniel Recht, Applied Physics, School of Engineering and Applied Sciences, Harvard University
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Pulsed laser melting, a powerful technique for producing new alloy materials, is typically a time-consuming and labor-intensive process. A computer-controlled sample positioning and data collection system was designed and built to improve the efficiency and reproducibility of this process. Three automated stages driven by stepper motors position samples with micron-scale precision. Data from high-speed photodiodes tracking laser pulse duration and sample melt duration is captured by a 500 MHz oscilloscope. A high-resolution beam profiling camera records the uniformity of every laser pulse. These instruments are integrated by a graphical user interface developed to facilitate user operation of the system. The improvements implemented are expected to speed sample production substantially.

Quantum Well Intermixing on a Hybrid Silicon or SiO_2 Bonded GaAs/InGaAs Platform

Mohsin Pasha, Electrical Engineering, University of Texas at Austin

NNIN REU Site: Nanotech@UCSB, University of California, Santa Barbara
NNIN REU Principal Investigator: John Bowers, Electrical Engineering, University of California, Santa Barbara
NNIN REU Mentor: Jock Bovington, Physics and Electrical Engineering, University of California, Santa Barbara
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Quantum well intermixing (QWI) allows one to controllably alter the bandgap in a semiconductor laser for use in photonic integrated circuits (PICs). QWI has been successfully implemented on various platforms to create higher bandwidth photodetectors, modulators, and tunable lasers. The success of QWI is determined by measuring the shift in wavelength of a sample's photoluminescence (PL). The focus of this project is to develop a successful QWI process for a hybrid silicon (Si) or SiO_2 bonded gallium arsenide/indium gallium arsenide (GaAs/InGaAs) laser platform. This low loss Si and $SiO_x(N_y)$ waveguides enable the world's longest integrated semiconductor lasers to displace currently used fiber in solid state lasers in terrain mapping LIDAR systems. The first part of this project was to develop a way to measure the sample's PL. The second part of this project was to induce the greatest wavelength shift through impurity free vacancy diffusion (IFVD).

Fabrication of Metal Wire Polarization Filters

Diana Bolser, Physics, University of Missouri-Columbia

NNIN REU Site: Nano Research Facility, Washington University in Saint Louis
NNIN REU Principal Investigator: Professor Viktor Gruev, Engineering and Applied Science, Washington University in St. Louis
NNIN REU Mentors: Timothy York and Raphael Njuguna, Engineering and Applied Science, Washington University in St. Louis
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Nanowires make good sensors because their small dimensions enhance their sensitivity. However, to be of use, nanowire sensors must be integrated with electronics capable of processing those signals. In this project, we demonstrated a method to fabricate arrays of small wire-grid optical polarization devices. Using photolithography and other experimental techniques, we developed a reliable procedure for producing silver wires with micron-scale features. This procedure was optimized in a variety of tests designed to achieve the best possible fabrication process. The polarization filters produced in this project are prototypes of much smaller arrays that will eventually be implemented directly in optical engineering devices.

Fabrication of Photonic Crystals for High Temperature Applications

Joseph DeWilde, Chemical Engineering, Oregon State University

NNIN REU Site: Nanofabrication Center, University of Minnesota-Twin Cities
NNIN REU Principal Investigator: Professor Andreas Stein, Department of Chemistry, University of Minnesota
NNIN REU Mentor: David Josephson, Department of Chemistry, University of Minnesota
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Photonic crystals are materials that possess a periodic structure on an optical length scale. Theoretical calculations have demonstrated that the thermal emission of tungsten photonic crystals with a specific, periodic structure can be modified to reduce the amount of blackbody infrared radiation from the material. This property has implications for improving the efficiency of thermal emission sources and for use in thermophotovoltaic devices. Pure tungsten photonic crystals were found to degrade at temperatures above 1000°C. For this reason, tungsten-coated carbon photonic crystals were used for their hypothesized thermal stability. Various chemical fabrication processes to create metallic photonic crystals were investigated. The photonic crystals were fabricated by: preparing a carbon substrate with periodic structure, altering the substrate by various means, and finally coating the substrate with tungsten metal via chemical vapor deposition. The structures of the resulting photonic crystals were then investigated. On the resulting 1 mm thick photonic crystals, tungsten deposits were found to a depth of about 150 microns. This depth could be sufficient for useful photonic applications.

Fabrication of High Speed Nanoscale Metal Semiconductor Metal Photodetector

Kevin Chen, Electrical Engineering, Arizona State University

NNIN REU Site: Colorado Nanofabrication Laboratory, University of Colorado at Boulder
NNIN REU Principal Investigators: Bart Van Zeghbroeck, EE, University of Colorado at Boulder; Paul Hale, NIST
NNIN REU Mentor: Zefram Marks, Electrical Engineering, University of Colorado at Boulder
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In this project, we fabricate an ultra-fast metal-semiconductor-metal (MSM) photodetector with bandwidth approaching a terahertz capable of measuring ultra-fast optical pulses. The bandwidth in a MSM photodetector is limited by both the transit-time required for the photogenerated carriers to reach the electrodes and the capacitance of the photodetector. To increase the speed, we introduce an array of metal nanodots in between the electrodes of the photodetector which will decrease the transit-time by acting as artificial recombination centers. Additionally the increased electrode spacing due to the nanodot array will decrease the capacitance of the device. The photodetector is fabricated on a substrate of gallium arsenide due to its standard use in the optoelectronics industry. An epitaxial layer of aluminum gallium arsenide was added to prevent electron-hole pair generation deep in the substrate to improve speed. Using electron beam lithography devices with feature sizes of less than 300 nm have been fabricated on a coplanar transmission line structure. An electro-optic sampling system at the National Institute of Standards and Technology (NIST) was used to measure the impulse response and bandwidth of the photodetectors.

Characterization of Biomolecular Interactions at the Silicon Photonics Biosensor Interface

Lauren Cummings, Chemical Engineering, Oregon State University

NNIN REU Site: Center for Nanotechnology, University of Washington
NNIN REU Principal Investigator: Dr. Daniel Ratner, Bioengineering, University of Washington
NNIN REU Mentor: Jeff Chamberlain, Bioengineering, University of Washington
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Through the development of real-time, label-free biosensing technologies, silicon (Si) photonics has revealed its potential to create a new paradigm for personalized medicine. Among the most promising biosensing devices to emerge from this field is the Si ring resonator. Similar to surface plasmon resonance, the ring resonator platform detects biomolecular binding events by measuring changes in the refractive index of its surrounding environment. A fundamental challenge to this promising technology is our limited understanding of biomolecular interactions at the biosensor interface. Past research has revealed that non-specific protein adhesion varies significantly as a function of surface chemistry and greatly influences the performance of biosensing platforms. As such, the investigation of protein-SiO_2 surface interactions is a critical step towards improving ring resonators as a bioanalytical tool. With this motivation, we utilized AFM to investigate the nanoscale phenomena of protein adsorption and to characterize Si substrates modified for biomolecular detection. Using carbohydrate-mediated protein adhesion as a validation model for the ring resonator platform, each stage of surface modification (cleaning, carbohydrate immobilization, lectin binding) was analyzed through AFM. Results were then supplemented with real-time binding experiments, offering further insight into functionalization techniques by revealing the kinetics of protein adhesion.

Gallium Phosphide Nanowires for Photoelectrochemical Hydrogen Generation

Clara Chow, Biomedical Engineering, University of Wisconsin - Madison

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University
NNIN REU Principal Investigator: H.-S. Philip Wong, Electrical Engineering, Stanford University
NNIN REU Mentors: Xinyu Bao and Jason Parker, Electrical Engineering, Stanford University
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Water splitting by III-V nanowire photoelectrochemical (PEC) cells is a promising approach to produce hydrogen for energy. In this process, gallium phosphide nanowires grown on silicon substrates by metal-organic chemical vapor deposition were chosen as the semiconducting electrode. Nanowires were chosen to increase contact surface area and improve extraction of photo-generated charge carriers in comparison to planar photovoltaic cells. Gallium phosphide was chosen for its sufficient band gap energy to drive water splitting and its ease of growth on silicon. The nanowires were assessed with a potentiostat in a 3-electrode compression cell. Photocurrent and gas bubbles were both observed, indicating hydrogen reduction in the cell. In addition, nanowire stability in the PEC cell was measured and degradation was not seen. Further optimization of nanowire growth, band gap, and substrates will improve performance in the PEC cell and increase the efficiency of hydrogen generation in this application.

Locomotion of Catalytic Nanomotors

Jesse Ault, Mechanical Engineering, Purdue University

NNIN REU Site: ASU NanoFab, Arizona State University
NNIN REU Principal Investigator: Dr. Jonathan Posner, Mechanical Engineering and Chemical Engr., Arizona State University
NNIN REU Mentor: Jeffrey Moran, Mechanical Engineering, Arizona State University
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Bimetallic nanomotors propel themselves autonomously in solutions of hydrogen peroxide. The asymmetric catalytic decomposition of hydrogen peroxide at the nanomotor surface creates a proton imbalance and self-generated electric field, driving fluid from the anode to the cathode. The velocities of these nanomotors have been shown to depend on the concentration of hydrogen peroxide in solution. The effective diffusivity of the nanomotors is controlled by the coupling of the nanomotors thermal, rotational, and translational diffusivities, as well as their advective velocities. We quantify the effective diffusivities of spherical bimetallic nanomotors by tracking the nanomotors position over long times (> 30 minutes) and calculating the root mean square displacement. We find that the motor's effective diffusivity depends on its diameter as well as the local fuel concentration. Self-propelled nanomotors offer the possibility for controlled drug delivery in the body and the mimicry of biological systems on the nanoscale.

Thermally Enhanced Dynamic Core Migration with Phase Change Materials

Amber Pizzo, Mechanical Engineering, Binghamton University

NNIN REU Site: Nanotechnology Research Center, Georgia Institute of Technology
NNIN REU Principal Investigator: Dr. Andrei Fedorov, School of Mechanical Engineering, Georgia Institute of Technology
NNIN REU Mentor: Craig Green, School of Mechanical Engineering, Georgia Institute of Technology
Contact: apizzo1@binghamton.edu, andrei.fedorov@me.gatech.edu, cgreen8@gatech.edu

Due to the presence of hotspots in microprocessors, localized cooling solutions have become a significant area of research. This study's aim was to fabricate a chip containing heaters of varying size, to simulate these hotspots. Resistance temperature devices (RTDs) were fabricated around these heaters to measure the temperature of the hotspots and the heat spread through the substrate. Pyrex® wafers were used as the substrate because its low thermal conductivity localizes the heating near the hotspot, minimizing spreading. The chip will be used to characterize the ability of various phase change materials (PCMs) to mitigate the effect of transient hotspots.

Fabrication included electron beam deposition, plasma enhanced chemical vapor deposition (PECVD), and reactive ion etching (RIE). Material deposition consisted of titanium, as a layer of adhesion, and platinum, as the sensing material. The devices were calibrated to determine the relationship between temperature and the electrical resistivity of the heaters and RTDs.

Ferroelectric Thin Films for Reconfigurable Radio Frequency Electronics in Next Generation Wireless Communications

Scott Bakkila, Physics / Computer Science, Lawrence Technological University

NNIN REU Site: Lurie Nanofabrication Facility, University of Michigan, Ann Arbor
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Ferroelectric materials exhibit field-dependent permittivity effects that are useful in making voltage-dependent capacitors (varactors) that can be applied to electronically tunable radio frequency circuits, tunable filter circuits, and other wireless communication devices. The purpose of these experiments is to maximize the tunability of ferroelectric thin-film capacitors by varying material process parameters. The materials used in these experiments are barium strontium titanate (BST) and barium titanate (BTO), and are deposited by pulsed laser deposition. Thin film deposition parameters under study are deposition and annealing temperature, oxygen partial pressure, laser energy, material thickness and material/deposition type. BST has shown lower current leakage allowing a higher applied electric field while BTO has shown a greater degree of dielectric tunability. Efforts to minimize the leakage in BTO while maintaining its tunability have included depositing a thin layer of BST on either side of a BTO deposition and depositing a thin amorphous "dead" layer of BTO at lower temperatures prior to a higher temperature deposition. Initial DC testing has yielded positive results with various deposition parameters which are being reproduced in the fabrication of capacitors with planar waveguide contacts for high frequency testing.

Generation of a "Clean" Surface on Metallic Nanoparticles for Reliable Toxicity Evaluation

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As nanotechnology progresses from research and development to commercialization and use, the associated risk of toxicity must be explored in well-controlled studies. To assess the safety of nanomaterials, it is necessary to establish reliable sources of nanomaterials and accurately characterize their properties. We are able to produce silver nanostructures with well-controlled size and shape using polyvinylpyrrolidone (PVP) as a capping ligand in a solution-phase synthesis. Various silver nanostructures are tested for their toxicity by a 40-hour assay in a solution consisting of synthetic media and saccharomyces cerevisiae, a yeast strain serving as a model eukaryote. A microplate reader monitors yeast growth where any inhibition can indicate the cytotoxicity of silver nanostructures. The studies have shown clear size- and shape-dependent cytotoxicity in yeast assays at a variety of concentrations. To show the validity of toxicity assays, full characterizations at different stages have been performed to reveal the physiochemical properties of silver nanostructures, including morphology, aggregation and cell uptake. The effect of capping ligand PVP on cytotoxicity has also been investigated with control on wash cycles and aging process. This study will help improve our understanding of how cells respond to specific nanoparticle parameters.

Synthetic Antiferromagnetic Nanoparticles for Biosensing

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Magnetic nanoparticles can be highly useful in many biological applications. The magnetic moments of these particles need to be large to provide large magnetic signal or to facilitate magnetic manipulation of biomolecules. In traditionally synthesized superparamagnetic nanoparticles, increasing the size of the particle increases the magnetic moment. Larger particles, however, do not always revert to a non-magnetic state when not in the presence of a magnetic field, making them non-ideal for work in biological systems. Synthetic antiferromagnetic (SAF) particles, however, achieve high moments at small sizes. In order to utilize this property of SAF particles, the fabrication process must be streamlined. In this study, particles are synthesized using a nanoimprint method followed by layered deposition of metals. The nanoimprint process is improved by using a spin coat polymer layer as the release layer rather than a metal, which requires deposition, thus saving fabrication time. The magnetism of SAF particles is measured using alternating gradient magnetometry (AGM). Once the process for synthesizing the SAF particles has been optimized, they can be functionalized for many different biological processes such as protein sorting or cancer signaling.

Growth of Graphene Nanostructures on Silicon Wafers

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Due to its optical properties, high electrical conductivity, and high mechanical strength, grapheme has attracted much interest in a variety of scientific and engineering applications. The project focuses on its use for Quantum Interference Control (QIC) devices. The QIC effect can be utilized to generate ballistic photocurrents in single layer graphene (SLG) through quantum mechanical interference of charge carriers excited by single- and two-photon absorption. Evaporated copper on silicon wafers was used as a catalyst for the chemical vapor deposition (CVD) growth of SLG. Photolithography techniques were employed to pattern QIC devices on the wafers, and the copper thin film was subsequently etched and undercut to achieve the suspended graphene bridge necessary for a QIC device. Resistance measurements were taken to characterize and compare various device geometries, with results as low as 30 kOhms. Devices with a wide variety of graphene bridge sizes, ranging from 5-15 microns wide and 0-16 microns long, with appropriate undercut have been achieved. Currently, optical characterization and testing of the devices is being performed, as well as optimization of the SLG growth process.

Heterogrowth Junction of Silicon-Germanium and Carbon Nitride

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Silicon-germanium ($Si_{1-x}Ge_x$) and carbon nitride (C_3N_4) nanowires (NWs) constitute promising building blocks for future electronic and medical applications respectively. $Si_{1-x}Ge_x$ energy band gap and thermal conductivity makes it very attractive for use in mobile communication applications. On a nearly strain-free material, the energy-band discontinuity of $Si_{1-x}Ge_x$ allows for enhanced speed and performance, allowing for a more defect free and smaller transistors. C_3N_4 has promising biological applications for the treatment of breast cancer. C_3N_4 nanowires conjugated to herceptin can selectively target breast cancer tissue cells.

$Si_{1-x}Ge_x$ and C_3N_4 nanowires were grown using chemical vapor deposition. Wires were grown on silicon substrates of <111> and <100> orientation with metal catalysts (Au, Ni, Al, Pt). Five percent silane (SiH_4) and high purity germane (GeH_4) were used for the synthesis of $Si_{1-x}Ge_x$ NWs. Carbon nitride nanowires were grown using high purity propane (C_3H_8) and ammonia (NH_3) gas. The synthesized nanowires were then studied by energy dispersion spectrum (EDS), and Raman and Auger spectroscopy. The size of the $Si_{1-x}Ge_x$ NWs are approximately a less than a micron in diameter with an average length more than 200 μm.

DNA Electrophoresis in Microfabricated Devices

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Deoxyribonucleic acid (DNA) separation by molecular weight in an electric field is a pillar of modern molecular biology techniques. Traditional agarose and polyacrylamide gels fail to resolve very long DNA fragments unless one employs, pulsed field gel electrophoresis, a slow method. Microfluidic devices containing arrays of micron-sized posts may offer an inexpensive and quick alternative to gels. Using photolithography techniques, we fabricated a silicon dioxide device consisting of two channels connected by a bend. Each channel contains a hexagonal array of differently sized and spaced posts (2 μm diameter with 6 μm center to center spacing and 1 μm diameter with 3 μm spacing). This transport phenomena research will improve our understanding of DNA electrophoresis and allow us to optimize geometries of microfluidic devices intended for large DNA separation.

Fabrication and Characterizations of Plasmonic Nanostructures for Organic Photovoltaics

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Metallic gratings with a periodicity in the subwavelength regime have been shown to produce a variety of effects. When combined with photovoltaics these nanogrids can lead to an increase in absorption at wavelengths that are dependent upon the periodicity of the grating. Gold gratings of periodicity 500 nm and 350 nm were fabricated using electron beam lithography. These periodicities were chosen to target the areas where our photovoltaic material had poor absorption when using a thin film. Thin film organic photovoltaics show potential to enable widespread use of solar energy. However, they currently have low carrier diffusion lengths and poor absorption. Thus, plasmonic enhancement of these photovoltaic materials provides a potential to greatly increase their efficiency for certain wavelengths. Fabrication techniques for the nanogrids and the application of the photoactive layer are presented, as well as absorption efficiencies for organic photovoltaics with and without plasmonic enhancement.

Surface Treatments to Control the Wettability of Photonic Crystal Bio-Sensors

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Photonic crystals offer a promising means of bio-sensing, because they can confine light to a small volume where its interaction with matter is very strong. As a result, the binding of even relatively few bio-molecules to receptors on the photonic crystal can significantly change the optical properties of the sensor. The binding events can be detected by monitoring resonant peak shifts in the transmission spectrum through the crystal. A crucial challenge in the sensing process is the treatment of the photonic crystal surface to ensure predictable spectrum shifts for analytes delivered in fluids. We investigate surface treatments for gallium phosphide and silicon nitride, two materials which are promising candidates for photonic crystal biosensors, in hopes of establishing reliable processes to control surface wettability. Using sessile drop contact angle measurements, we monitor the relative hydrophobicity or hydrophillicity of each treated surface. We assess the thickness and structure of any deposited layers with a spectroscopic ellipsometer and an atomic force microscope, respectively. A high degree of surface control enables effective delivery of the bio-molecules for enhanced detection sensitivity and provides guidelines for the design of optimized fabrication steps for future devices.

Surface Analysis of DNA Microarrays

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Surface bound deoxyribonucleic acid (DNA)-based arrays have shown the potential to be powerful tools for both the diagnosis and analysis of several different diseases. However, for microarrays to meet their theoretical expectations for detection sensitivity and the potential for single base mutation detection, the current technologies need to be optimized. Sensitivity refers to the ability to detect small concentrations of specific DNA strands in solution, and is related to the hybridization efficiencies of the DNA on the array. Selectivity refers to how accurately the array works in the presence of competing binding agents. The purpose of this study is to analyze DNA arrays in order to determine the source of the problems in the current methods. This is achieved through surface analysis techniques such as SPR, time-of-flight secondary ion mass spectrometry (ToF-SIMS), and x-ray photoelectron spectroscopy (XPS). In addition, fluorescent imaging is used to evaluate individual spot uniformity within an array on a commercial substrate. ToF-SIMS is used to verify the fluorescence findings. Preliminary results suggest that there may be an issue with sample storage of this particular commercial substrate that correlates to a problem with reproducibility.

Top-Down Fabrication of Patterned Vertically Aligned Silicon Nanowires

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Silicon nanowires (SiNWs) have recently attracted significant attention due to their one-dimensional structure [1] and semiconducting properties [2]. With many potential applications in micro- and nano-electro-mechanical systems (M/NEMS) [3], the development of various SiNW conformations is a popular area of current research. This study investigates the fabrication of hierarchically patterned assemblies of vertical SiNWs by a two-step etching process. The first step in the fabrication process involves basic photolithography and deep reactive ion etching (DRIE) to form Si micropillars on a Si wafer. The following step consists of metal-assisted chemical etching of Si in a solution of hydrofluoric acid and silver nitrate [4]. To selectively control this etching and form SiNWs from the individual micropillars, an etch mask is required. Various masks were tested, and the results showed a Teflon®-like polymer deposited by DRIE from C_4F_8 plasma produced an effective mask. To form hexagonally-ordered SiNW arrays, a self-assembled monolayer of closely-packed polystyrene nanospheres (500 nm diameter) is formed and acts as a shadow mask to selectively etch the silicon substrate. The results showed this process as a potential method of obtaining monodisperse, diameter-controlled SiNWs in the near future. Last, a study of the metal-assisted etching process on flat substrates was performed by varying the etch parameters.

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Portable Diagnostic Systems for the Purification and Detection of Biomolecules

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A microfluidic based integrated system was designed for the purification and detection of target ribonucleic acid (RNA) from crude samples. The prominent features of this system include low-cost, rapid test time, and suitability for multiplexing. For purification, streptavidin conjugated glass beads (diameter 100-00 μm) and target specific biotinylated probes were used to separate target RNA from samples. Thereafter, a biobarcode method was used for the detection of purified RNA. Different functionalization chemistries were used to conjugate streptavidin on the surface of glass beads. The microfluidic channel was made of a low-cost polydimethylsiloxane (PDMS) material and a 20 μm nylon membrane was used for the entrapment of beads inside the channels. As a model, we selected cucumber mosaic virus, which is of enormous significance in plant pathology. The plants were inoculated with this virus and after two weeks, the symptomatic leaves were picked for the extraction and detection of virus with the system.

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Molecular Specific Biosensing Based on Engineered Quasi-3D Nanostructures Used for Cancer Diagnostics

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Surface-enhanced raman scattering (SERS) was investigated using various nanopatterns, such as nanoholes and nanorectangles. The enhancement factor was calculated for each of these patterns on different substrates, silicon and indium tin oxide (ITO) coated glass. It was determined that the choice of substrate makes a difference for the enhancement factor of the pattern, based on differences in optical properties of the two substrates. The goal is to obtain the maximum Raman enhancement for each pattern and be able to detect and identify different types of bacteria, both pathogenic and non-pathogenic. The detection of a single bacterium can be done using Raman spectroscopy with a 785 nm laser focused over the bacterium. By having a monolayer of bacteria over a nanopattern, the Raman spectrum taken will be the average Raman spectra for the species of bacteria and will allow for direct identification using SERS. The next step using this technology is to detect and compare normal tissue cells and cancer cells in both a dry and microfluidic environment.

Immunomagnetic Detection of Circulating Tumor Cells using a Microfluidic Chip

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Early recognition of cancer cells within a patient has proven to be a key component in successful treatment and survival. Given a blood sample containing circulating tumor cells (CTCs), these cells can be marked with ion oxide nanoparticles using a specific functionalization process. By running this prepared sample through a system that includes a microfluidic chip and a magnet, the labeled CTCs can be captured for analysis. Using three different dyes and exposure types, identification of a CTC is based on physical characteristics and appearances as they are observed under each exposure condition. Possible tumor cells are photographed under each condition for reference as the images are used together for identification. Although CTCs possess a unique physical appearance in terms of fluorescence, size and shape, correct identification can be a challenging task. After working with several persons trained in cell identification, a tool was developed in MATLAB to facilitate the identification of CTCs based on the measurements and calculations for key characteristics as taken from the experiment images. By using implicit definitions for identification, a large volume of images can be analyzed quickly and efficiently while also ensuring judgment of each cell is based on the same criteria.

Single-Layer Graphene Contacts to Pentacene OTFTs

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Organic thin-film transistors (OTFTs) have attracted significant interest in recent years as their performance approaches that of traditional amorphous silicon and polycrystalline silicon-based electronics. They are especially promising for large-area, flexible, and low-cost circuitry, such as organic light-emitting diode displays and RFID tags. Despite recent improvements, however, traditional gold-contact OTFTs still stuffer from somewhat poor performance, in part because of their large contact resistance.

We propose single-layer graphene as a novel contact material for pentacene-based OTFTs. Graphene, a two-dimensional hexagonal lattice of carbon, is an ideal contact material for OTFTs because of its monolayer thickness and similar atomic structure to pentacene, and yet it remains almost entirely unexplored in this application. Leveraging our group's established expertise in large-scale graphene production, we demonstrate the fabrication of effective graphene-pentacene contacts and explore their electrical properties and the nature of the contact interface.

Advanced Chip-to-Chip Interconnect

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As modern electronics decrease in size, one of the major problems which arise is the signal delay between the transistor and substrate through the current tin-based solder sphere connections. Specific issues with solder include brittle copper-tin intermetallics, high parasitic capacitance of associated underfill, and poor electromigration resistance. The focus of the project is to replace solder spheres with all-copper (Cu) pillar interconnects. The pillars are to be grown from a Cu seed area on each chip via Cu electroplating, and are then bonded together via electroless Cu plating. Further stabilization of the bond results from polymer collars, annealing processes, and optimization of the copper electroplating and electroless copper plating conditions. Various electroplating bath conditions were tested to form flat or dome-ended Cu pillars. Similarly, various electroless plating bath conditions were tested to achieve the greatest all-copper bond strength. These experiments took place on both processed wafers and on actual microchips. The wafer process began with a silicon wafer, on which we grew a SiO_2 layer, sputtered Cr, Cu, and Ti layers, grew another SiO_2 layer, and spun two photoresist layers. After exposure, the photoresist layers form either single or daisy-chained polymer collars around each copper pillar, depending on the mask set used for exposure.

Fabrication of MTJs Based Spintronic Devices

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Limitations in complementary metal-oxide-semiconductor (CMOS) technology, such as scalability and power consumption, are increasing the demand for alternative or hybrid technologies. One promising approach is magnetic quantum-dot cellular automata (MQCA), which is nonvolatile and lower power. MQCA consist of nanomagnets that have two stable magnetic directions which correspond to 1 and 0. The nanomagnets are placed in close proximity to one another (~ 30 nm) so that they are magnetically coupled. Since they are magnetically coupled, logic can be performed by switching an input nanomanget, which causes a chain reaction of switching in the other elements in a domino fashion. Limited experimental demonstrations have been done with single magnetic layers that showed the primitive Boolean logic functions; however, they could only be read with magnetic force microscopes. We fabricated MQCA logic with magnetic tunnel junctions (MTJs) which will allow us to utilize magnetic resistance to measure operation in real time, speed, and reliability for the first me. Electron-beam lithography was used to pattern 100 × 200 nm features and contact electrodes. Alignment was achieved which allowed us to make contact between individual elements and electrodes. Experimentally demonstrating MR based MQCA is essential in order for these devices to become a viable candidate for the next generation of logic.

Low Stress Oxides for use in Microfabricated Ion Traps for Quantum Computation

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Trapped atomic ions are a leading technology for performing quantum computation. The Brown Lab, in collaboration with the Quantum Information System group at the Georgia Tech Research Institute, is fabricating surface-electrode radiofrequency ion traps for trapping and controlling calcium ions. These traps have a thick layer of oxide (about 15-20 μm) for insulation. The internal stresses of the oxide will be further aggravated by the extreme change in temperature when the trap is cooled down to low Kelvin temperatures. Thus, there is potential for the oxide to buckle, thereby distorting the trap. Reducing the stress in the film minimizes the possibility of the oxide buckling. The focus of this project is to create a recipe for the lowest stress oxide on one specific plasma enhanced CVD tool. Baseline stress measurements of the standard recipes were taken and parameters such as pressure, RF power, gas ratios and gas flow rates were changed to optimize the stress.

Process Development for Writing sub-100 nm Line Widths Using a Scanning Electron Microscope

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Lithography is a process whereby a polymer resist is selectively exposed to some form of radiant energy such as ultraviolet (UV) light or, in our case, a concentrated beam of electrons. Although photolithography has a higher throughput, only electron-beam lithography (EBL) can produce line widths under 30 nm. To circumvent the restrictive costs associated with dedicated EBL systems, our lab paired an existing JEOL 6360-LV scanning electron microscope (SEM) with a RAITH ELPHY lithography system. Our goal was to determine the minimum line widths that could be written with this setup. A diluted solution of 950,000 MW PMMA, when spun at 3000 RPM, created a 60 nm thick resist layer on a silicon wafer. An acceleration voltage of 30 kV and a working distance of 10 mm were kept constant while the beam spot size was varied between 10 and 45 (equivalent to a beam current range of 0.19 pA to 67 pA) and the dosage was varied from 90 uAs/cm^2 to 9000 uAs/cm^2. A minimum line width of 100 nm was obtained, and after evaporating a 10 nm layer of chrome onto the sample and performing liftoff, we observed metalized lines that were measured to be 120 nm, with the discrepancy being due to chrome buildup along the non-vertical resist sidewalls.

Fabrication of a Gallium Nitride NanoFET

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The complementary metal oxide field effect transistor (CMOSFET) continues to be an impacting device within the semiconductor industry. Known for its amplification and switch-like capabilities, the CMOSFET has great significance in logic circuits. Miniaturizing such technology to the "nanolevel" has been of great interest to the industry. We will demonstrate the use of a gallium nitride (GaN) nanoFET as a long term solution to the physical limits performed by silicon CMOS technology. Our process of fabrication is as follows; a highly doped-low resistant silicon wafer was thermally oxidized on one side to form silicon dioxide (SiO_2), which acts as the gate dielectric. Photolithography was then performed to define the drain and source contacts. The source and drain are formed by a lift-off process using aluminum. Evaporation of aluminum on the reverse side of substrate forms the back gate electrode. GaN nanowires grown by chemical vapor deposition (CVD) are then suspended in toluene. Using a syringe, the suspension was then dropped on to the surface containing the source and drain. Nanowires lying across a source and drain complete the nanoFET. I-V characterization at different temperatures is performed using a probe station.

Characterization of High Aspect Ratio Silver Micromachining for Tunable Radio Frequency Filters

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This paper reports on full characterization of silver electroplating and polishing processes for the implementation of low-loss integrated inductors. Silver is used as the conductor material as it exhibits the highest electrical conductivity of all metals. Electroplating conventionally deposits a thick layer of a metal on a substrate by passing an electrical current between them inside an electrolyte. Depending on the type of electric current, the electroplating process can be classified into three categories: direct, pulse, and pulse-reverse. While direct current electroplating usually offers the highest deposition rate, pulse-reverse electroplating decreases the porosity of the electroplated regions and improves the overall surface uniformity. Therefore, in this study, we have characterized pulse-reverse electroplating of silver and compared the results with direct electroplating. We demonstrated an overall uniformity of better than 0.4 μm using pulse-reverse plating into a 10 μm thick photoresist mold with a deposition rate 19% faster than direct plating. To reduce the surface roughness and further increase the uniformity, we utilized a silver polishing process and characterized the polishing rate with a 0.3 μm aluminum slurry, hydrogen peroxide, and ammonium hydroxide solution. Even though we primarily processed the samples with photoresist molds, this method can be used with higher aspect ratio silicon molds enabling thick, fast, and uniform deposition of silver.

Lifetime of Charge Carries in Silicon Nanowires

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Silicon based technology has created many sophisticated devices and systems by scaling down the device size in the past several decades. It now has many challenges to continue this trend. Nanowires, especially silicon nanowires might be a solution. Due to their small size, nanowires may have new properties and physics which have not been understood very well. For example, lifetime of charge carriers is one of the key parameters that determine the performance of semiconducting optoelectronic devices such as photodiode and solar cells. But the lifetime in silicon nanowire devices may be very different from that of the conventional bulky counterparts. Under the supervision of Dr. Yaping Dan and Prof. Crozier, we are investigating this difference during the summer program. We first used the standard photolithographic process to electrically contact a silicon nanowire and then employed scanning photocurrent microscopy (SPCM) to measure the lifetime. The SPCM uses a nanosized laser to scan over the nanowire. The laser excites the charge carriers (electron-hole pairs) and hence photocurrent at appropriate bias. The position of the laser and the photocurrent are recording simultaneously. From the position-photocurrent relation, we can extract the diffusion length of electrons or holes which is proportional to their lifetime. We find the diffusion lengths in silicon nanowires are roughly equal to the nanowire diameters (< 100 nm) while it is known that this value in the bulky silicon devices is approximately a few micrometers. The short diffusion lengths (hence short lifetime) might originate from the surface recombination because nanowires have a very high surface-to-volume ratio. This hypothesis is still under investigation.

Three-Dimensional Super-Resolution Using a Phase Mask Fabricated via Grey-Level Lithography

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Three dimensional (3D) super-resolution can be achieved in microscopy instruments by means of phase masks that shape the point spread function. Grey level lithography is an attractive procedure for the generation of these phase masks. The photolithographic phase masks (PPM) encode the light emitted from a specimen via a topographical index of refraction variation consisting of a series of phase-singularities. In our case, the mask produces a double helix point-spread function (DH-PSF), which allows for the estimation of the object position throughout the depth of focus of a typical system. The goal of this project is to fabricate a PPM mask and to determine the best methods for its characterization. We manipulate the grey-scale lithography capabilities of the SF-100 Xpress system by priming the photoresist with multiple exposures prior to the final exposure pattern. This procedure allows us to produce the desired topography expressed by the photoresist after exposure and development (with feature sizes on the order of 10^{-6}m). Upon testing these phase masks in an optical system, we are able to observe the desired DH-PSF. Currently, experiments are being done to translate the fabricated topography of the photoresist into quartz through reactive ion etching.

Probing Nano-Scale Volumes and Vesicular Membrane Solvent Dynamics Via Selective Enhancement of Nuclear Magnetic Resonance Signal by Dynamic Nuclear Polarization

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Lipid vesicles have been spotlighted as potential drug delivery mechanisms and as models for cellular compartments, but few methods characterize the behavior of encapsulated solvents, either in terms of exchange or in terms of local dynamics inside the vesicle [1]. Work using nuclear magnetic resonance (NMR) spectroscopy, enhanced by dynamic nuclear polarization (DNP), characterizes dynamics of water near an electron spin label, and can selectively measure local dynamics within 5-16Å of a covalently tethered spin label [2]. In the opposite extreme, NMR diffusion measurements measure diffusion of bulk solvents [3]. By contrast, our method seeks to characterize the dynamics of a solvent encapsulated in nano-scale vesicles, which are dispersed in a dilute solution. This is achieved by employing vesicles designed to encapsulate spin label. DNP enhances sensitivity to NMR signal from the intra-vesicular volume, against the background signal of the much larger bulk solvent, facilitating elucidation of dynamics of trapped solvents, as well as their exchange with the bulk.

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Micropore Immunosensors for Fast Disease Diagnostics

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Single molecule biosensors using etched silicon micropores provide an alternative to, and an advantage over, traditional immunoassays. By reducing the volume necessary for the assay and supplying an electrical readout of the measurements, the silicon micropore system reduces the cost, time, and chemical reagents involved in current standard immunoassays. These differences, as well as the portable nature of the biosensor, make it ideal for point-of-care diagnostics. A microbead-based assay was performed by applying a constant voltage and detecting the reduction in current when silica beads were passed though the micropore. Silicon pores with a topside diameter of 5 μm and backside diameter of 100 μm were fabricated using a series of photolithography processes and a deep silicon reactive ion etcher. The detection of the translocation of the beads through the pore through resistive pulse measurements is similar to the method used for Coulter Counting. Silica beads and the micropore itself were then functionalized with an antibody specific to the antigen being tested for, in this case Interleukin-6. In the presence of a sufficient concentration of the antigen, the functionalized beads bound inside of the pore and caused a sustained reduction in the measured current.

Designing Nano-Engineered Substrates to Probe Cell Organization, Motion and Traction Forces

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Interactions between cells and their environments involve both chemical signals and mechanical forces. Cellular mechanical forces play a key role in variety of cellular processes, such as cell migration and cell mitosis, however they are much less understood than the chemical aspects. Additionally, these mechanical forces are likely altered in diseased tissues and may present new diagnostic and treatment opportunities. The present study aims to develop a device to measure the forces cells exert on their environments, particularly the traction forces cancerous cells exert as they migrate. To accomplish this, we developed deformable gels that have embedded beads and a specific and adjustable stiffness. The deformation of the gel is detected by movement of the embedded beads and is related to the force applied by the cells. A method was developed to characterize the elastic modulus of the gel by applying magnetic forces to magnetic beads coupled to the gel surface. The present study has begun characterization of the cancer cells' response to the mechanical environment of the gel, and has established a technique to begin cell traction force measurements.

Fabrication of Gold Nanoparticles Using Electron Beam Lithography: Effect of Development Conditions on Shape and Resolution

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Due to the short wavelengths of electrons relative to those of light photons used in optical lithography, electron beam lithography (EBL) is an extremely high-resolution lithographic process. Importantly, however, the overall resolution achieved is also greatly affected by the development conditions used. The purpose of the work described in this paper is to determine the optimal development conditions for the fabrication of rectangular gold nanoparticles. Silicon wafer substrates were coated with a polymer resist (PMMA) prior to exposure to the electron beam used to write the desired pattern via EBL. Following exposure, the substrates underwent development. The developers tested were solutions comprised of different mixtures of MIBK:IPA (methyl isobutyl ketone: isopropyl alcohol), ranging from a MIBK:IPA ratio of 1:3 (v/v) to pure IPA. Although the 1:3 MIBK:IPA developer produced the highest-resolution particles (determined by imaging via scanning electron microscopy), the samples developed with pure IPA yielded particles of acceptable resolution as well.

Response of Microorganisms to Cu-Doped TiO_2 Nanoparticles Under Different Light Conditions

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Shewanella oneidensis MR-1 is an environmental bacterium that can reduce metals. *Mycobacterium smegmatis* is a pathogenic bacterium, but a non-virulent species. Titanium dioxide (TiO_2) based nanoparticles, commonly used as catalysts, have photocatalytic properties that allow the nanoparticles to absorb ultraviolet (UV) light. The results showed that neither the TiO_2 nor the Cu-doped TiO_2 nanoparticles reduced the viability of *S. oneidensis* MR-1 under dark or fluorescent light conditions because the bacterium has evolved the strong capability to reduce metal ions and oxidative stresses. *S. oneidensis* MR-1 is highly sensitive to UV light, but the presence of TiO_2 nanoparticles or Cu-doped TiO_2 nanoparticles dramatically increased the viability of *S. oneidensis* MR-1. The 1% Cu-doped TiO_2 nanoparticles had the greatest increase in cell survival by nearly 196-fold. *M. smegmatis* showed a dramatic decrease in viability at a higher doping amount of Cu-doped TiO_2 nanoparticles. The UV light absorbing properties and aggregation of the nanoparticles may contribute to our findings. Varying the particle size and compositions of the TiO_2 based nanoparticles could adjust the light absorbance and light scattering properties.

Porous Microbeads as 3D Scaffolds for Tissue Engineering

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Tissue engineering seeks to create replacements for tissues and organs, in an effort to maintain, improve, and regain biological functions. Three dimensional (3D) porous scaffolds are commonly used to enhance cell attachment, facilitate nutrient and oxygen transport, and create a suitable microenvironment for proper cell activities. Recently, microbeads with interconnecting inner and outer pores have been studied as a viable carrier scaffold for better implants. However, the difficulty lies in making microbeads with large enough pores for cells to grow inside. This project aims to (1) fabricate uniform porous poly (lactic-co-glycolic acid) microbeads using a fluidic device, (2) seed mouse fibroblasts into these beads, and (3) culture the cell-loaded beads in a mold of a desired shape. We have been able to demonstrate the success of fibroblasts in attaching and proliferating in porous beads with average pore diameters of around 30 μm. The fibroblast-loaded beads were able to connect to neighboring beads by a network of cells to form a tissue construct in the shape of a fabricated mold, confirming the possibility of creating tissues of a specific shape to better fit an injury site.

Cell Viability and Morphology on Carbon Nanotube Microstructures

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Carbon nanotubes (CNT) are cylindrical macromolecules of carbon, and have unique mechanical, electrical, and thermal properties. Due to their outstanding properties, there are very wide applications of CNT such as electronics, mechanical, energy, and biomedical applications. In particular, CNTs could be used for studies of cell mechanotransduction, as scaffolds for tissue engineering, for regulation of stem cell differentiation, and for intracellular tracking and labeling. The objectives of this program are to investigate the structural interaction between CNT micro-pillars structures and cells, CNT-biomolecule composite and cells because there are few studies of cell behavior on the multi-scale geometries of CNT forests. Two dimensional patterned vertically aligned CNT were growth on catalyst annealed substrates by chemical vapor deposition (CVD) method and then, made in to 3-dimensional shapes by densification. After fabrication of the substrates, mouse fibroblast (3T3) cells were seeded and cultured for several days. This study focused on cell adhesion, morphology and viability on the substrate with CNT and CNT-fibronectin. Cells were highly attached to CNT-fibronectin composite than non-composited CNT, and morphology of cells were changed on CNT micro-pillars compared to catalyst annealed substrates. In addition, cells were capable of growth on CNT-fibronectin micro-pillars.

High Resolution SPR Microscopy Based Microarray

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Surface plasmon resonance (SPR) is a valuable tool for monitoring changes in local optical properties near a sensor surface. SPR-based instruments are commercially available for the label free detection of molecular binding events, providing real-time kinetic characterization of molecular interactions without the use of an antibody tag. We present a novel SPR detection platform that combines the high spatial resolution of microscopy-based SPR imaging with a low volume, high temporal resolution microfluidic flow system. A variety of fluid flow configurations and flow cell geometries were modeled and fabricated to achieve kinetic resolutions of greater than 2 s^{-1}, more than twice as fast as commercially available SPR biosensors. Additionally, minimal sample volume ($< 1\ \mu L$) is consumed in the current set-up. Reduction of sample volume and increased sensitivity are crucial improvements toward integrating SPR technology into small point-of-care diagnostic devices which can detect smaller sample concentrations without the need for chemical tags, rapidly analyze drug-antigen affinity, or characterize the effectiveness of antiviral drugs.

Nanotherapeutics for Advanced Cancer Disease

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Plasmonic nanoparticles are gaining increased attention for use in biological systems due to their versatile, tunable optical properties [1]. In particular, gold nanorods can be tuned to specifically absorb light in the near infrared region, at wavelengths which do not harm living tissues. The absorbed infrared energy is then dissipated as heat from the nanorods to their surroundings. Sufficient heating within living tissues can induce hyperthermic cell death due to hyperthermic temperatures (> 43°C) [2]. Delivery of these nanoparticles to cancerous cells at concentrations that will be responsive to treatment from an infrared laser is key. This project demonstrates that gold nanorods coated with branched cationic polymers synthesized in our laboratory can be employed to deliver plasmid DNA to PC3 prostate cancer cells, leading to transgene expression. Ongoing work explores the use of gold nanorods for simultaneously administering laser-induced hyperthermia and delivering therapeutic genes to cancer cells.

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Semiconductor Nanocrystal Inks for Printed Photovoltaics

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Copper indium gallium diselenide (CIGS) is an effective light-absorbing material for photovoltaic devices (PVs). Commercially fabricated CIGS film devices are vapor-deposited, which has been cost prohibitive. A different approach to CIGS film deposition is to formulate an nanocrystal ink dispersed in a solvent that can be coated onto the substrate under ambient conditions. The method's goal is to generate layers with desired composition without the need for vacuum or high temperature processing. Such an approach would greatly reduce the complexity and cost of CIGS deposition. Recently we have fabricated solar cells from spray-deposited CIGS nanocrystal inks with efficiency up to 3.1%. The nanocrystal films are deposited from a spray gun, and thus, one of the limiting factors in device efficiency is the significant variation of nanocrystal film thickness that occurs across the substrate. To provide better control over film thickness and uniformity, we have developed a new automated deposition apparatus. The influence of the deposition conditions, such as the tip-to-substrate separation, raster pattern, flow rate, spray pressure, dispersion concentration, and spray angle on the film quality was examined by optical and scanning electron microscopy of the deposited films. The morphology of the films was then correlated with the dimensionless Reynolds and Weber numbers of the process.

Template Stripping for High Thoughput Fabrication of Nanohole Arrays

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Surface Plasmons (SPs) are electromagnetic waves created at a metal interface that interact strongly with photons near the interface. SPs can be excited by periodic nanohole arrays (NHAs) in an optically thick metal film, which leads to extraordinary optical transmission effects through the nanoholes. Currently, ordered NHAs are fabricated on a small scale using focused ion beam lithography (FIB). Small-scale fabrication of NHAs is expensive and leads to low throughput and high variability among samples. The purpose of this project was to develop a method to produce NHAs on a large scale in a manner that is repeatable and inexpensive. NHAs were produced by creating a silicon mold with the desired hole pattern using electron beam lithography followed by reactive ion etching and wet chemical etching. A thin layer of silver was deposited on the surface of the silicon mold and stripped off using an epoxy. This method, known as Template Stripping, produced square arrays up to 64 holes on a side with diameters ranging from 150 nm to 220 nm in 100 nm thick silver film. The arrays exhibited optical characteristics comparable to FIB NHAs over multiple samples created from the same mold.

Growth and Characterization of Nanoparticle Enhanced Tunnel Junctions

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Multijunction solar cells employ tunnel junctions to interconnect the serially-connected p/n junctions. ErAs nanoparticle enhanced tunnel junctions, grown on GaAs, have Schottky like tunneling barriers that show substantial improvements in tunneling current density, when compared to conventional p/n junctions. Future multi-junction solar cells incorporate dilute nitrides to achieve technologically significant band gaps, which require thermal annealing to remove point defects from the GaInNAs lattice. Preliminary data indicates that post growth thermal annealing can enhance the tunneling currents of nanoparticle-enhanced tunnel junctions; however, thermal annealing has not been carefully studied. We are performing the first careful study of thermal annealing, investigating the roles of annealing time and temperature on tunnel junction resistance. We also highlight potential applications of these tunnel junctions to semiconductor lasers.

Aluminum Induced Crystallization of Silicon on Quartz for Silicon Wire Array Solar Cells

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Radial junction silicon wire array solar cells are being developed as an inexpensive and potentially more efficient alternative to planar silicon solar cells. Currently, silicon wires are grown on bulk silicon substrates, an expensive commodity. Aluminum induced crystallization (AIC) of silicon on quartz was studied as a low cost substitute for bulk silicon wafers for wire array growth. Samples were prepared with a quartz / 100 nm Al / 100 nm amorphous Si (a-Si) structure, and were annealed in nitrogen at 550°C to facilitate Al/Si layer transfer and Si crystallization. The effects of Al oxidation time and the a-Si deposition method on crystallization were investigated. It was found that a-Si deposited by e-beam evaporation produced more consistent crystallization compared to hydrogenated a-Si deposited by plasma enhanced chemical vapor deposition. Crystallized Si regions up to 50 μm in size were obtained for samples in which the Al was exposed to air for several days prior to a-Si deposition and annealing. X-ray diffraction and Raman spectrometry analysis confirmed the formation of polycrystalline silicon islands with Si<111> orientation, which is preferred for the growth of vertical silicon nanowires. Samples with successful Al-Si layer exchange were then tested as a substrate for silicon nanowire growth.

Effect of Surface Pre-Treatments on Initial Stages of Tantalum Nitride Atomic Layer Deposition

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As features sizes in integrated circuits approach the nanometer scale, there is an increasing need for highly conformal, precisely-controlled thin film deposition. Atomic layer deposition (ALD) has emerged as an ideal method to deposit a variety of materials used in modern semiconductor devices. At the same time, many materials remain difficult to deposit via ALD because chemical interactions at the thin film-substrate interface govern the initial stages of nucleation and growth in ALD. This project investigated ALD of tantalum nitride, one of the most attractive materials for diffusion barriers between copper interconnects and the dielectrics that surround them. Growth on both copper and porous low-κ dielectrics was studied, and pre-treatments were identified to promote growth in the early stages of ALD. Tantalum nitride nucleation was drastically improved on copper with hydrogen plasma or ammonia pre-treatments, while oxygen plasma pre-treatment inhibited it. From these results, it was concluded that copper oxide layers as thin as a few nanometers inhibit ALD. Deposition on untreated porous low-κ resulted in poor growth and tantalum nitride diffusion into the dielectric, but a polyethyleneimine capping layer improved deposition rates and increased surface nucleation, likely by increasing the number of active sites on the surface.

Nanoethics Research and Ethics Education Implementation

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Fifty years of research and development in nano-scale science and technology have created increasing awareness in the general public of possible nanotechnology applications. Due to concerns about scientific misconduct, such as biomedical research fraud, and socially destabilizing uses of scientific advances, like human cloning, federally funded nano-research is mandated to include a component of Social and Ethical Implications (SEI) research and education. As a contribution to SEI studies, it is useful to review nanoethics history, education, and culture within the scientific community. The goals of such a review include promoting ethics understanding within the nano-scientific community as well as encouraging communication between nanoscientists and society. To accomplish these goals, we will explore the history of nanotechnology itself as well as parallel developments in applied ethics. Also, we will investigate new ways to emphasize ethics within research labs by means of enhanced website content and the development of an ethics checklist. The checklist will follow concise steps to guide researchers through specific ethical considerations at appropriate pause points, and ultimately provide a systematic platform for maintaining efficient and effective ethics practices. Overall, this review of ethics in the field of nano-scale science and technology will contribute to maintaining appropriate levels of trust among scientists themselves and between the scientific community and society at large.

The Nano Influence: Perspectives of Nanotechnologists on How They Shape the World Around Us

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The National Nanotechnology Infrastructure Network has begun to support research on topics of societal and ethical implications of nanotechnology, also known as SEI or nanoethics. This project aims to collect information from researchers on their current perspectives on nanoethics. The motivation is to develop better educational tools and programs specifically for the nanotechnology community. The study consisted of a survey and a discussion group involving members of the Colorado Nanofabrication Lab at University of Colorado at Boulder, and the Renewable Energy Materials Research Science and Engineering Center at Colorado School of Mines. The survey gathered some general data about the ethical atmosphere at these facilities, and asked such questions as ‘What motivates your research?’ and ‘Do any ethical issues affect the way you do research?’ A discussion group functioned as a potential model or educational tool for future use with an additional exit survey taken to gauge if interests or perspectives had changed as a result of discussion group participation. Preliminary results suggest that opinions on ethical issues of technology are broad, but also that not many engineers are exposed to engineering ethics coursework. This information will be useful in planning engineering ethics curricula in universities across the United States.

Societal and Ethical Issues (SEI) Public Service Posters

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Nanotechnology is a quickly expanding and interdisciplinary field with numerous current and potential applications. Due to nanotechnology’s significant current and potential impact on society, the National Nanotechnology Infrastructure Network (NNIN) recognizes the importance of promoting consideration and awareness of the societal and ethical implications of nanotechnology among its facilities’ users. The goal of the project was to develop a series of posters encouraging NNIN laboratory users to consider the societal and ethical implications of their research, and to encourage a more socially-oriented outlook among users. The poster messages are designed to employ users’ motivations to do research to stimulate SEI consideration, especially with regard to maximizing the benefits and reducing the potential societal risks of their work. Existing literature on the motivations of scientists and engineers, in conjunction with focus groups with Cornell NanoScale Science and Technology Facility (CNF) users provided insight into users’ motivations to work in nanotechnology. Messages were designed based on these insights, and then tested in another focus group. Revised messages were used to develop initial posters, which were tested in a final focus group. Several thematically-integrated posters were finalized, and they will be placed in the fourteen NNIN sites across the country.

Material Characterization of Advanced III-V Semiconductors for Nanophotonic Integration

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New applications for integrated nanophotonic components and circuits typically found in telecommunication and internet data transfer will utilize tunable microwave filters for the pre-filtering and channelizing of information in the RF domain. Such applications will require the use of high optical saturation power quantum well designs in order to reduce detrimental nonlinear phenomena. The goal of this project is to experimentally characterize novel quantum well designs and extract material parameters to guide future design work. By fabricating and testing broad area laser structures, the material loss and gain parameters are extracted. We have fabricated broad area laser structures using a standard wet-etch process defining surface ridge waveguides. The P-metal pattern was first established using contact lithography and then deposited by e-beam evaporation followed by metal liftoff. Material characterization was performed using a pulse setup and cleave-back approach to determine light-current-voltage characteristics and differential efficiencies. Net internal optical loss and characteristic gain values were then calculated. Internal optical loss values as low as 4.175 cm^{-1} and characteristic gain values as low as 15.152 cm^{-1} have been recorded.

Characterization of Materials with Epitaxially Embedded Nanoinclusions for Thermoelectric Applications

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The engineering of thermoelectric materials for better electrical and thermal properties is an essential part of increasing the efficiency of thermoelectric modules and generators. To understand the behavior of candidate material systems, characterization of electrical and thermal transport properties is of paramount importance. In this work, comparisons between measurements and numerical simulations of the ZT parameters of III-V semiconductor compounds doped with rare-earth semimetal nanoparticles are reported. These parameters include Seebeck coefficient, electrical conductivity, and thermal conductivity, all of which are temperature dependent. Additionally, we report on the implementation of the 3ω method for measurement of the thermal conductivity of thin films. At the time of this writing, proof-of-concept tests for the thermal conductivity of silicon dioxide thin films on sapphire substrates were successfully completed.

Mechanics of 1-25 nm Thin Films

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Nanoscale thin films are used in a wide array of technologies, ranging from computer processing to solar panels. However, many elements of classical mechanics across multiple domains begin to falter at the nanoscale. The purpose of this project is to fabricate a device capable of testing stress-strain, electrical, and thermal properties of a wide range of free standing thin films within a transmission electron microscope (TEM) environment. Using various photolithography, deposition, and etching techniques, devices were fabricated with free standing platinum thin films. *In situ* TEM experiments on high current-density electromigration in 100 nm platinum thin films were conducted. The specimen began with very small, randomly oriented grains approximately 5 nm in size. Current was slowly increased from 100 μAmps to 10 mAmps over the course of three and a half hour. Almost instantaneous grain growth was observed at 10 mAmps. After passing this current for several minutes, average grain size approached 100 nm and dislocation pile-up was observed. Selected area electron diffraction (SAED) patterns show grain rotation to the {111} plane during the grain growth. Using the methods and devices developed in this project, a vast array of experiments on nanoscale thin films can be conducted.

Characterization of Ag-Si Composite for Infrared Photodetectors

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In general, this project seeks to characterize the response to infrared radiation of a composite made of silver nanoparticles embedded in silicon for possible use in photodetectors. The use of small particles, about 16 nm in diameter, allows enhanced efficiency in capturing photons. The composite is fabricated using a magnetron sputtering system which deposits it on a silicon substrate. This study specifically looked at the effects of oxygen, annealing, and composite layer thickness on the response. Responses were measured at room and liquid nitrogen temperature. Annealing and short exposure to oxygen were found to greatly improve the responsivity. Signals have been measured as high as a few volts and at wavelengths as long as 1.2 μm.

Characterization of Iron Oxide Integration within Phospholipid Encapsulated Colloids

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Contrast agents for magnetic resonance imaging (MRI) enhance the visibility of targeted tissues and cells. Many current T_1-weighted (T_1w) contrast agents (bright) are gadolinium-based; however, these have been associated with nephrogenic systemic fibrosis, a severe connective tissue disease, among patients with impaired kidney function. Iron oxides are common non-gadolinium nanoparticles used for dark MRI imaging (T_2*-weighted). They can provide strong negative contrast due to their strong magnetic field interference, but the persistence of these particles in the blood stream prevents imaging for 24 to 48 hours post-injection, until the circulating metal oxide has cleared.

Colloidal iron oxide nanoparticles (CION) entrap magnetite particles within the inner aspect of a monolipid layer, yielding a bright MR contrast agent that can be imaged an hour post-injection. Our model suggests that this depends upon use of a weakly magnetic iron isolated along the internal particle periphery. While chemical cross-linking of the iron oxide particles with the lipid membrane has been effective, new chemical formulation approaches to achieve a self-assembly product are desirable. This project examined the utility of transmission electron microscopy (TEM) to characterize the spontaneous distribution of lipid-modified iron oxides into the hydrophobic surfactant of CION for development of a new chemical synthesis.

Sputtered TiW/W Emitter Contact Stack Design in Terahertz Bipolar Transistors

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The conditions under which the emitter contact metal of a mesa-type bipolar transistor is sputter-deposited influence the contact's stress and sheet resistance, which in turn affect the transistor's structural stability and bandwidth, respectively. Through aggressive scaling of emitter dimensions, emitter-base and base-collector junction capacitances are reduced and high RF bandwidth can be realized; however, this scaling results in a high aspect ratio emitter contact, which requires low stress for structural stability. The purpose of this project is to develop a recipe for use in a sputtering tool that satisfies both the low stress and low resistance requirements for the contact. It has been found that the most significant factors in determining the characteristics of interest of the resultant sputtered film are the working pressure of the deposition chamber and the working temperature of the substrate. The desired resistance has been obtained via low working pressure and elevated working temperature, while preliminary experiments indicate the desired stress can be obtained via compensation between the titanium-tungsten alloy and tungsten layers of the emitter contact. By using tensile stress in the tungsten layer and compressive stress in the titanium-tungsten layer, fabrication of bipolar transistors with bandwidths in excess of one Terahertz is possible.

Optimization of Ohmic Contacts to III-N Semiconductor Material

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High electron mobility transistors (HEMTs) are a class of devices which achieve higher power and higher frequency operation than possible on silicon. In the AlGaN- and AlInN-GaN heterostructures studied, electric current is confined within a thin conductive sheet 30 nm below the surface of the otherwise resistive material. This property makes the problem of contacting this two dimensional electron gas (2DEG) from outside the device nontrivial. Present approaches rely on depositing and then annealing metal stacks chosen for their electrical and chemical properties, such as Ti-Al-Mo-Au. In this process, metal diffuses into the material, and donor sites are created by the out-diffusion of nitrogen, increasing conductivity. This study involves depositing, annealing, and testing novel metal stacks to optimize these solid state reactions with the goal of minimizing contact resistance. A separate approach was also tried in which holes were etched through the conductive plane prior to metal deposition. These nanoperforations allow the deposited metals to directly contact the conductive plane through the AlGaN or AlInN barrier layer.

Graphene Nanoribbons as Transistors in Nanoelectronic Devices

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As technology has advanced, the scientific community has strived to make electronics smaller and more efficient; finding an adequate material to help miniaturize electrical devices is an important task in the further development of technology. Graphene nanoribbons (GNRs) may be an alternative to silicon semiconductors in electronics because of their novel electronic and spin transport properties, and also because GNRs less than 10 nm wide have a band-gap suitable for making field-effect transistors (FETs). This project focuses on fabricating devices on high quality GNRs made by unzipping multiwalled carbon nanotubes (MWNTs) in order to understand the effect of structure on nanoelectronic device performance. The substrates for making GNR devices are 300 nm SiO_2/Si with markers made by photolithography, dry etching, and oxidation. Atomic force microscope (AFM) is used to locate the GNRs and measure the width and thickness of GNRs. After the location, three-terminal nanoelecronic devices can be fabricated on these GNRs. The properties of the devices are measured using probe station in vacuum at room temperature. The relationship between width, thickness of GNRs and the performance of the devices are studied. The device fabrication and properties studied during the project are important for understanding how GNRs can be developed and used in future nanoelectronic applications.

Heterogeneous Integration of p- and n-type Nanowires for Complementary Nanowire Circuits

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Nanowires have shown promising results for use in creating future electronic devices that go beyond the end of MOSFET scaling and for the use in three dimensional complementary circuits. Our efforts here focus on the optimization of the nanowire contact printing method, a critical step for fabricating nanowire field-effect transistors. The results of the contact printing show a high transfer density of seven well aligned 20 nm diameter SnO_2 nanowires per micrometer and eight well aligned 20 nm diameter Ge/Si core/shell nanowires per micrometer. The parameters of the contact printing optimized here are the applied pressure of the nanowires on the substrate, the lubricant applied to the nanowires, the distance traveled by the substrates and the average speed of the transfer process. We also demonstrate and study simple nanowire field effect transistors based on these optimization efforts which show comparable performance to previously constructed devices. Using these optimized parameters a simple integration process can be used to combine two types of nanowire field effect transistors, one SnO_2 n-type and the other Ge/Si core/shell p-type for possible three dimensional complementary nanowire circuit applications.

Fabrication of Locally-Gated Bilayer Graphene Field Effect Transistors

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Bilayer graphene, composed of two carbon monolayers in Bernal stacking, displays the unique property of having a bandgap that is tunable by electric fields. The development of local gating will enable higher gating efficiency and local control of the charge carrier density and band gap in bilayer graphene.

We fabricate bilayer graphene field effect transistors with local backgates. Gate patterns are printed onto SiO_2/Si wafers using optical lithography. The SiO_2 layer is then partially removed by reactive ion etching to carve the desired structure. Metal deposition of the gate electrode followed by atomic layer deposition of a HfO_2 dielectric layer complete the gate stacks. Since graphene conforms to the morphology of the substrate, a smooth HfO_2 surface is critical to obtaining highly smooth graphene. The surface roughness of the HfO_2 is directly controlled by the surface roughness of the SiO_2 produced by the initial reactive ion etching. We explore the parameters of different etching recipes to achieve a smooth SiO_2 surface. Etched SiO_2 exhibits a root mean square (RMS) surface roughness of 5.12 Å. Bilayer graphene exfoliated onto the completed gate stacks displays a RMS roughness of 5.82 Å.

Multimodal Optical and MRI Studies with Multifunctional Spinel Nanoparticles

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Superparamagnetic iron oxide nanoparticles (SPIONs) are the subject of many recent studies in biological imaging but limited reports concerning the biomedical applications of the related spinel metal ferrites, MFe_2O_4, are available. Magnetic resonance imaging (MRI) and optical imaging are commonly used medical imaging techniques to visualize the internal structures of the body and molecular events in tissues. Together, the exceptionally high spatial resolution provided by MRI notably complements the high detection sensitivity of optical methods. Thus, a multimodal imaging approach that combines both reporting strategies would allow assessment of molecular processes in tissue and accurate localization of signal source by optical and MRI methods, respectively. To accomplish these goals, materials that can unify both optical and MRI signals are needed. Spinel ferrite nanoparticles possess enhanced magnetic properties and have already been reported as effective contrast agents for improved MRI sensitivity. By combining their magnetic capacity with an activatable fluorescent dye, we are developing a tissue-specific multimodal nanoprobe that harnesses the individual strengths of these molecular imaging techniques and compensates for their weaknesses.

Transferring CVD Grown Graphene

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The unique properties of single layer graphene make it a strong candidate for electrical, mechanical, and chemical applications. With recent breakthroughs in growing large area graphene sheets via chemical vapor deposition (CVD), industrial scale applications of graphene now seem plausible. In order to bridge the gap of innovative research with the commercialization of graphene products, it is crucial to develop techniques transferring large area graphene sheets grown on copper foils to various target substrates. The first portion of our research focused on the use of poly(methyl methacrylate) (PMMA) as a graphene carrier. We investigated different methods for contacting the graphene to the substrate, along with different methods to remove the PMMA to obtain cleaner graphene. We also explored using thermal release tape (TRT) as a graphene carrier, varying TRT adhesion strengths. By varying different transfer parameters, we were able to begin the assessment of which methods yielded the best quality of graphene specific to each application.

Adhesion of Capillary Underfill Epoxies for Flip Chip Packaging

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Flip chip packaging is a popular means of compactly connecting microchips to their external circuitry. However, environmental factors often compromise the adhesive strength of capillary underfill epoxies used to seal and support the region between microchips and their substrates in such assemblies. In this study the effects of humidity and temperature on the adhesion of bisphenol-F underfill epoxies with and without ductility-increasing flexibilizers are investigated, as well as hybrid adhesion layers that may alleviate epoxy debonding. Double cantilever beam fracture mechanics tests that quantify adhesion of the epoxies to silicon under various humidity levels and temperatures reveal that environmental conditions drastically alter the mechanical strength of the epoxies. Also, considering the potential that organic-inorganic zirconium hybrid layer (Zr HL) sol-gels hold as adhesion promoters, the sol-gel preparation procedure is optimized for more reliable sol-gel integration into epoxy-silicon interfaces. Preliminary data indicate Zr HL fracture energy sensitivity to various preparation parameters involving cure time, cure temperature, and sol-gel aging. Ultimately, understanding an optimized sol-gel preparation procedure, as well as the adverse effects of standard processing and operating conditions such as changes in moisture levels and temperatures on flip chip assembly epoxies, will benefit the development of microelectronics with high-performance adhesion.

Magnetic Domain Wall in Nanobridges of Ultrathin Manganite Films

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Research into spintronics has led to many discoveries that are unexpected and exotic. Some of these discoveries have already been implemented as electronic devices, most prominently as computer read heads and magnetic random access memories, yet there is still much more to be uncovered and understood. The anomalous magnetoresistance of magnetic domain walls discovered in strained manganite films cannot yet be fully explained and it is towards this understanding that we strive towards. This study is on the fabrication and testing of constricted nanobridges made of manganite thin films that exhibit low-field magnetoresistance (LFMR). Two different methods of fabrication are tested. The first method uses electron beam lithography and the second uses focused ion beam (FIB) milling. Both methods use standard photolithography for larger patterning. The nanobridges are made in varying widths and lengths, with the goal of restricting the number of magnetic domains present for simpler analysis. These devices are in the end phases of production. The smallest bridge fabricated using e-beam lithography measures at 100 nm while focused ion beam milling produce bridges of 50 nm in length. Initial tests show that there is a definitive magnetoresistance present in the devices.

Ion Distribution in Ionomer and High Temperature Ionic Liquid Actuators

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Proper understanding of the ion transport and concentration distribution in low voltage ionomer-based actuators is crucial for optimizing their performance in medical and optical devices. Actuators were built using Aquivion™ swelled with ionic liquid of 1-butyl-2,3-dimethylimidazolium chloride (BMMI Cl). Electrical impedance, I-V characteristics, and charging current for the actuator were characterized using a potentiostat at both room temperature and above the 99°C melting point for BMMI Cl. The DC conductivity of the actuator was found to be 30 μS/cm at 100°C and two orders of magnitude higher, compared to room temperature measurements. The electrochemical window of the device was determined to be 3V. Bending actuation under 2.5 V was observed at > 90°C but not at room temperature. Charge accumulation was measured to be one order of magnitude greater at 100°C compared to room temperature. A semi-quantitative depth profile of ion concentration was measured by using SIMS imaging at the PSU Chemistry Department. Depth profiling suggests that, in a charged actuator, concentration gradients for $BMMI^+$ are thicker compared to corresponding Cl^- gradients. The charged actuator also demonstrates unexpected accumulation of Cl^- in the cathode and $BMMI^+$ in the anode which is likely caused by clustering effects.

Suspended Graphene Structures on Silicon Carbide Substrates

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Graphene exhibits promising electrical and thermal properties which may lead to applications in high speed and flexible electronic devices. Graphene is an atomically-thin planar sheet of sp^2-bonded carbon atoms arranged in a hexagonal lattice. A novel approach was developed to produce suspended graphene structures for transmission electron microscope (TEM) analysis. TEM analysis will determine the structural and electronic quality of the graphene at the atomic scale. The graphene sample is produced on the silicon face of silicon carbide by controlled sublimation of the silicon atoms. A film of silicon nitride is attached to the patterned graphene. Subsequently, a photoelectrochemical etch is employed to release the graphene from the silicon carbide substrate. The success of the process requires the optimization of various interrelated steps. A discussion of the fabrication process and results will be presented.

Plasmonic Nanoparticle Dimer Sensors

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Plasmonic nanoparticles are promising candidates for a variety of biological and medical applications. In this project, we explore actuatable nanoparticle dimers as sensors for small molecules, employing the distance dependence of hybridized plasmon resonance. Here, the energy of the dimer plasmon mode is related to the strength of plasmon coupling, which depends on the particle separation distance. By linking the nanoparticles with oligonucleotides that can undergo geometric changes, we detect the analyte via a spectral shift in the dimer plasmon resonance. Specifically, we consider the intercalation of daunorubicin into DNA-functionalized gold nanoparticle dimers. As daunorubicin lengthens the DNA linker by distorting the helical structure, the separation distance between particles increases, resulting in the weakening of plasmon coupling and a blue shift in the plasmon resonance wavelength. We observe an average blue shift for DNA sequences where the drug is expected to intercalate, with the magnitude of the shift dependent on the number of possible intercalation sites in the DNA sequence. Lastly, we address the potential of dimer sensors for the detection of chiral molecules.

Synthesis and Characterization of Oxide Embedded and Surface Passivated Silicon Nanocrystals

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Silicon (Si) nanocrystals emit light at the nanoscale, a phenomenon that is being utilized for proof-of-concept biomedical and optoelectronic applications. Quantum confinement effects govern the light emission properties for Si, but the size at which quantum confinement effects subside to bulk electronic properties is still unclear. Here, we elucidate the size at which quantum confinement effects vanish in Si nanocrystals by measuring the photoluminescence properties of Si nanocrystals with diameters greater than the Bohr exciton radius (5 nm), the size at which quantum confinement effects are proposed to emerge. Using hydrogen silsequioxane as a Si nanocrystal precursor, we fabricate thin film and bulk oxide embedded, and surface passivated Si nanocrystals. Photoluminescence spectroscopy shows the nanocrystal emission red-shifts and decreases in intensity with increasing nanocrystal size. We show that Si nanocrystals in excess of 5 nm are photoluminescent, an observation that has yet to be described in the literature.

Silicon Phononic Crystals for High Efficiency Thermoelectrics

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Thermoelectric materials can generate an electric current in response to an applied temperature gradient (Seebeck effect), or cause cooling in response to an applied current (Peltier effect). For thermoelectrics to be useful in application higher efficiencies must be attained. This project focuses on developing phononic crystals with a feature size of roughly 20 nm, utilizing a phononic band gap to decrease thermal conductivity, in order to achieve never before attained thermoelectric efficiencies. The first phase of this project tested masking materials which could be used as a mask to provide the selective etching which is required. A wet etching process using a solution of silver nitrate and hydrofluoric acid was used to etch silicon yielding the high aspect ratios necessary. Different metals (Ni, Ti, Cr) were evaporated onto a silicon wafer patterned with photolithography to test their decomposition rates. Chromium was the most promising mask tested and SEM showed successful selective shielding of the silicon, only allowing etching to the exposed parts of the sample. Currently a block copolymer template is being used to pattern chromium evaporation onto the silicon in order to yield the desired feature sizes (20 nm). A device is also being constructed to test the final thermoelectric material.

Controlling Nanoscale Electronic Variability in ZnO:Al Transparent Conducting Films

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The work function of transparent conducting oxides is critical in determining charge transfer in solar cells and diodes. Previous research has indicated that this quantity is not well-described by the known properties of bulk ZnO:Al, and may be strongly affected by the grain boundaries. We have used Kelvin force microscopy for nanometer resolution measurements of the work function, which is found to vary significantly on and off the grain boundaries. Our results show that work function granularity increases with oxygen content, due to the oxygen species segregated at the grain boundaries. This suggests that the work function can be tuned with post-processing treatments. Both exposure to UV/ozone and annealing in a hydrogen gas atmosphere affected the mean work function of the material and the electronic granularity. It remains to be seen whether these treatments can be used to increase the efficiency of optoelectronic devices.

Temperature Dependent Growth Properties of Epitaxial Graphene on (000¹) on Silicon Carbide

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The use of silicon-based transistors has been a staple in computer technology for decades, but due to fundamental material and device limits, progress in chip speed and computing power has begun to slow. Graphene-based transistors have the potential to break through these limitations and put us back on the path of increased performance gains with scaling. As a first step towards implementing graphene technology, it is necessary to have high-quality graphene sheets from which a chip with billions of devices can be fabricated. In this work, graphene was grown by silicon submiliation from the (000¹) face of helium-4 (^{4}He) silicon carbide (SiC) using a high temperature vacuum furnace. Both substrate preparation and growth processes were experimented with—variables included temperature and soak time. After growth, samples were characterized in a number of ways to determine sample quality, including Raman spectroscopy, atomic force microscopy (AFM) imaging, van der Pauw testing and Hall testing. An optimal temperature and soak time was determined that minimized sheet resistance while maintaining surface integrity.

Tuning Graphene Conductivity Using Inorganic Binding Peptides

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Single-layer graphene has emerged as a promising material in post-silicon nano-electronics as a result of its unique electronic properties. Due to its two dimensional (2D) structure, graphene is highly sensitive, and thus localized surface disturbances can effectively modify its electronic structure and conductivity. We have found certain inorganic peptides to successfully bind to multi and single layer graphene surfaces. In this project, we investigate the doping effects these binding peptides have on single-layer graphene made by micro-mechanical exfoliation. Using Raman spectroscopy, we can monitor the changes in electronic structure by observing the shifts in the characteristic G and 2D Peaks of graphene spectra after peptide incubation. We compare the types of doping caused by various peptide mutants. We also examine the degree of doping as it relates to different peptide solution concentrations and incubation times. We found that different peptides cause distinct shifts in the G and 2D peaks, revealing information on their unique doping capabilities.

Engineering Bacterial Proteins for Design of Self-Assembled Nanostructures

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Of the current methods used to build nanostructures, self-assembly is attractive because it can be highly specific and does not require specialized machinery, which makes it simpler and less costly. Deoxyribonucleic acid (DNA)-binding proteins are promising building blocks for self-assembly due to their tolerance for genetic manipulation and inherent affinity for DNA, a self-assembling biological polymer. This project explored the suitability of the *S. typhimurium* dsDNA binding protein SlyA (17kDa) for use as an engineered bi-functional protein to organize inorganic materials on a DNA scaffold. Molecular cloning was used to insert the coding sequence for a gold binding peptide (GBP1-7x or AuBP2) into the SlyA gene. Protein purification was used to isolate SlyA and SlyA gold binding derivatives, both with a 10x His-tag that was subsequently removed using Factor Xa protease. The binding of purified SlyA gold binding derivatives to 15 nm gold nanoparticles (AuNPs) was characterized via localized surface plasmon resonance (LSPR) spectrometry. Future work includes determining the SlyA gold binding derivatives' DNA affinity to ensure addition of a gold binding motif does not eliminate the protein's original DNA-binding function.

Development of Advanced Carbon Electrodes for use in Microfluidic Vanadium Redox Fuel Cells

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We report on the current progress to develop advanced carbon electrodes with improved performance in microfluidic vanadium redox cells. In vanadium cells, carbon electrodes are used as a catalyst as well as a conductor. Typical carbon paper electrodes have had a silver nanolayer applied to function as an integrated current collector. This resulted in a 34.2 % decrease in sheet resistance. In addition, carbon electrodes were fabricated using pyrolized micropatterened polyamide-imide films. The micropatterened films are designed to have a smaller pore size than the carbon paper electrodes, allowing for shorter diffusional distances, reducing mass transport losses. These advancements should decrease ohmic losses and increase the performance of the microfluidic fuel cell.

Real Time Blood Coagulation Sensor

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Non-compressible hemorrhage is the leading cause of potentially survivable deaths from combat injuries in Operation Iraqi Freedom. In trauma injuries, naturally produced coagulation proteins are quickly depleted, which can lead to hemorrhage-related death. We report a method of measuring blood coagulation in real time using microelectromechanical systems (MEMs)-based small-size, portable, and disposable devices. The devices utilize contour-mode acoustic waves to measure viscosity change in real time. The contour mode film bulk acoustic resonator (CFBAR) is a suspended ring-shaped piezoelectric layer of aluminum nitride thin film, sandwiched between two metal films. The CFBAR is excited in its radial directions and has a low motional resistance when coupled with liquids, allowing the device to maintain a high quality factor (Q) in liquids, up to 189. The high Q offers high sensitivity to the viscosity change during the coagulation process. The resonant frequency of the CFBAR sensor is sensitive to both surface mass loading and viscosity change of the coupling liquid. Using differential measurement technique, we have monitored the real time viscosity change of the full blood coagulation process. This report concludes that the CFBAR is a promising blood coagulation monitor and indicator, which would aid medics in the field.

Fabrication of Three Terminal Nanomechanical Graphene Switch

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Graphene is a single atomic sheet of graphite. It has superior electrical, mechanical and thermal properties. The high Young's Modulus, extremely low mass, low resistivity and planar surface make suspended graphene ideally suited for a NEMS based switch, which can be used for memory design or computational elements.
The device geometry consists of a graphene sheet in electrical contact with a gold electrode suspended over a silicon/SiO_2 substrate. The substrate is fabricated using standard photolithography and graphene is suspended by means of mechanical exfoliation. Voltage applied to the underlying silicon substrate is used to actuate the switch. Both optical resonance and electrical measurements will be taken to characterize the device.

Encapsulation of Single Cells in a Droplet-Based Microfluidic Device

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Microfluidic devices have great potential in cell analysis due to their small scale, high-throughput operation, and adaptability to a variety of analytical methods. A droplet-based microfluidic device, when combined with electrochemical measurements, would allow for more robust single-cell measurements than conventional electrochemical methods, thus better revealing cellular functions and dynamics. For this idea to be beneficial, cells must be individually encapsulated and stored in droplets of media in a continuous carrier phase, and high-throughput encapsulation of single cells is necessary. Therefore, this encapsulation process is tested and evaluated in this project. Soft-lithography techniques are used for PDMS-based chip fabrication. Tris buffer and perfluorinated polymer solution are utilized as the media and carrier phase, respectively. Lastly, polystyrene beads are used to simulate cells. The devices have a high percentage of one-cell droplets, showing their potential to be useful for single cell measurements. Ultimately, microelectrodes will be integrated into this device to produce an ideal tool for electrochemical measurements of immune cell exocytosis.

Improving Quality Factor of Drum Resonators via Gas Confinement

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The frequency of micro and nanoscale devices is sensitive to stress, force and mass, which makes the devices useful for applications in chemical and biological sensing. The ability to resolve small changes in frequency is dependent on the quality factor, Q, a measure of how much energy is lost relative to the stored energy of the resonator. One type of resonator, drum-type, loses energy through mechanical movement (squeeze film damping) and acoustics (sound radiation), both of which negatively impact Q.

Drum resonators were fabricated with a self aligning glass cap to prevent the formation of sound waves and minimize energy loss. The mechanical resonance of the devices was optically detected. At atmosphere, high frequency devices show larger improvements in Q than low frequency devices. An investigation into theory explains the enhancement of quality factor with the addition of the glass cap.

Measurement and Analysis of Blood Platelet Activation within a Microfluidic Device

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Cardiovascular disease (CVD) is the leading cause of death in the United States. In CVD, slow accumulation of fat and plaque within blood vessels forms a local constriction, known as a stenosis, whose flow conditions make it prone to clot formation and subsequent occlusion resulting in heart attack or stroke. We have developed an *in vitro* microfluidic device to model arterial flow conditions in stenosis clot formation. Microfluidic chips were molded from a milled master in polydimethylsiloxane (PDMS), bonded to glass, and treated with collagen overnight. Heparinized porcine blood was flowed through the device at shear rates of 500 s^{-1}, 1,000 s^{-1}, 6,500 s^{-1}, and 10,000 s^{-1}, conditions representing normal to pathological patient conditions. *In vitro* clot formation was monitored using simultaneous readings of mass flow and light transmission. Additionally, scanning electron microscopy (SEM) was utilized to visualize the activation-related morphological changes in individual platelets and platelet aggregates over time as well as under varying shear rates before and within our device. Our device allows for high throughput, simultaneous evaluation of clotting behavior over a large range of multiple shear rates, while SEM provides a visual confirmation of platelet behavior.

High Spatial Resolution Kelvin Probe Force Microscopy with Shielded Probes

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Kelvin probe force microscopy (KPFM) is a powerful technique to study electrical properties of materials on the nanoscale, but its spatial resolution is inherently limited by the long range of the electrostatic interaction. In this study, we mitigate these resolution limitations by electrically shielding the cantilever and the bulk of the tip. Shielded probes were created by coating conducting atomic force microscopy probes with an insulating layer followed by a conducting layer. The tip of the probe was then exposed by gas enhanced focused ion beam milling. The external metal layer forms a grounded electrical shield that extends to within 2 μm of the tip. The improvement in resolution due to shielding was analyzed using finite element electrostatic simulation. We find an 8x improvement in the short range (40% to 60%) step resolution and a nearly 40x improvement in the long range (25% to 75%) step resolution. We present preliminary experimental data comparing the spatial resolution of shielded and unshielded probes.

Characterization of Hg and Cu Capped Monolayers

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One bottom up approach to nanotechnology is molecular self assembly. This process is useful in the creation of highly packed molecules on gold (Au)(111) surfaces. A certain class of molecules, phenyl thiols are being exploited as molecular wires because electrons freely flow through their π-system and they easily bond with gold. We self-assembled 4,4'-dimercaptobiphenyl dithiol (DMBP) on a Au(111) substrate, and characterized them by ellipsometry, Auger spectroscopy, and surface probe microscopy. The average thickness of the monolayer measured by ellipsometry is consistent with chemisorbed DMBP monolayer that terminates with a free thiol. The DMBP monolayers were further reacted with solutions of either copper $(Cu)^{+2}$ or mercury $(Hg)^{+2}$ via an oxidation-reduction reaction resulting in either DMBP-Cu^{+1} or DMBP-Hg^{+1}, we use Auger spectroscopy to prove the presence of Cu and Hg. The expectation is that electrons in DMBP will flow through the π-systems of phenyl groups, the d orbitals of the terminating sulphur and finally through either the Cu or Hg. We investigated the redox behaviour of the Cu capped and Hg capped monolayer to see if the difference between the oxidation reduction behaviour of Cu and Hg would affect the electron flow within the monolayer. AFM and STM images confirm the surface order, and provide a visual picture of local features such as domain boundaries, steps and single molecular defects. STM was also used to characterize the electrical properties of monolayers. We made an effort to use STM to probe how the monolayers performed electrochemically.

Laminated Anodes and Electron Transport Layers for Inverted Organic Bulk Heterojunction Solar Cells

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Organic photovoltaic cells based upon bulk heterojunctions (BHJ) have great promise due to their low cost, flexibility, and solution processability. The photoactive layer of these devices consists of a phase-separated layer of electron donating and electron accepting materials within a common solvent; in this case poly(3-hexylthiophene): phenyl-C61-butyric acid methyl ester (P3HT:PCBM). Top-illuminated devices are of interest in commercial applications that require the use of an opaque or translucent substrate. This project involves the fabrication and characterization of laminated anodes utilizing indium tin oxide (ITO), poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS), and PEDOT:PSS with ethylene glycol (EG) in various configurations. Zinc tin oxide (ZTO) is a solution processed n-type semiconductor that is being widely investigated for in the LCD industry. Its solution processability, high electron mobility, and favorable energy band alignment with PCBM makes it a potential candidate as an electron transport layer within BHJ solar cells.

Fabrication of Recessed Bond Pad for Scalable Multiplexed Ion Traps

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Ion traps are the key component for atomic ion based quantum computers. A scalable ion trap quantum computer will require many electrodes to control the electric field for confinement and manipulation of ion positions. Laser beams are also required to control and measure the internal state of the ion. Wire bonds connecting the device and signal source can limit available laser paths. In this study, we fabricate the recessed bond pads allowing for optimal laser beam access to the ions. The recessed area is formed by anisotropic silicon etching. After formation of the recessed area, it is quite difficult to spin coat the photoresist (PR) at the edge of the recess. Two methods were employed to improve PR coating: minimization of edge curvature and PR planarization. First, we reduced the curvature of the edge, which may reduce the surface tension, and by both KOH and hydrofluoric-nitric-acid (HNA) etching. Both of them successfully changed the corner edge curvature, but the edge was still not covered by PR. The second method filled negative features with PR for planarization before spin coating. This method significantly improved the corner edge coverage. Finally, the bond pads were fabricated by chemical etching using the PR as a etching mask.

Fabrication of Graphene Structures Using an Atomic Force Microscope

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Graphene has been theoretically and experimentally shown to display exceptional thermal, electrical and mechanical properties to potentially revolutionize modern electromechanical devices. Despite the possibilities, the capabilities of this two dimensional (2D) crystal have yet to be harnessed due to limitations on fabrication techniques and large-scale manufacturing processes. To address these limitations, we investigated a graphene etching technique known as anodic oxidation using an atomic force microscope (AFM). By applying a voltage between the AFM tip and substrate, an electrochemical reaction is induced between the water meniscus and graphene causing it to locally oxidize. This technique allows one to pattern graphene on a sub-100 nm scale at a fraction of the time and cost of other methods. Line-widths of the etched graphene were roughly 40 nm with aspect ratios as high as 1:40. Graphene Van Der Pauw structures will be fabricated on top of 300 nm silicon nitride membranes. Chemical vapor deposition (CVD) grown graphene will be transferred onto the nitride membranes and Cr/Au electrodes will be evaporated onto the graphene. The graphene will then be then patterned into specified dimensions for the Van Der Pauw structures. The structures will be electrically tested and characterized in order to measure the sheet resistance of graphene.

Investigation of the Effects of Base Diffusion in Molecular Glass Photoresist Films

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This project explores strategies to reduce line edge roughness (LER) in photolithography. Molecular glass (MG) photoresists are used, as opposed to traditional polymeric ones. These smaller MG molecules have high glass transition temperatures as well as the potential to produce higher resolution. One probable cause of LER is acid diffusion in the post exposure bake step, which leads to blur and widening of lines. This undesirable effect is counteracted by introducing a small concentration of base in the resist mixture. Base in the unexposed region has more effect because there is a lot less acid there. Conversely, the effect in the exposed area will be minimal due to the much larger amount of acid there. This approach involves new base molecules with larger cores that exhibit decreased diffusion. Acid diffusion has been studied a lot, but base diffusion has not, and that is the present focus: a comparison of lithographic performance between these larger bases and traditional smaller bases. These systems were characterized via 254 nm contrast curves and deep-UV stepper exposure arrays. Etch rate studies with CF_4, CHF_3, and SF_6 were also performed.